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MATTER AND FORCE:

A COURSE

OF

LECTURES ON PHYSICS,

BY

J. K. MACOMBER.

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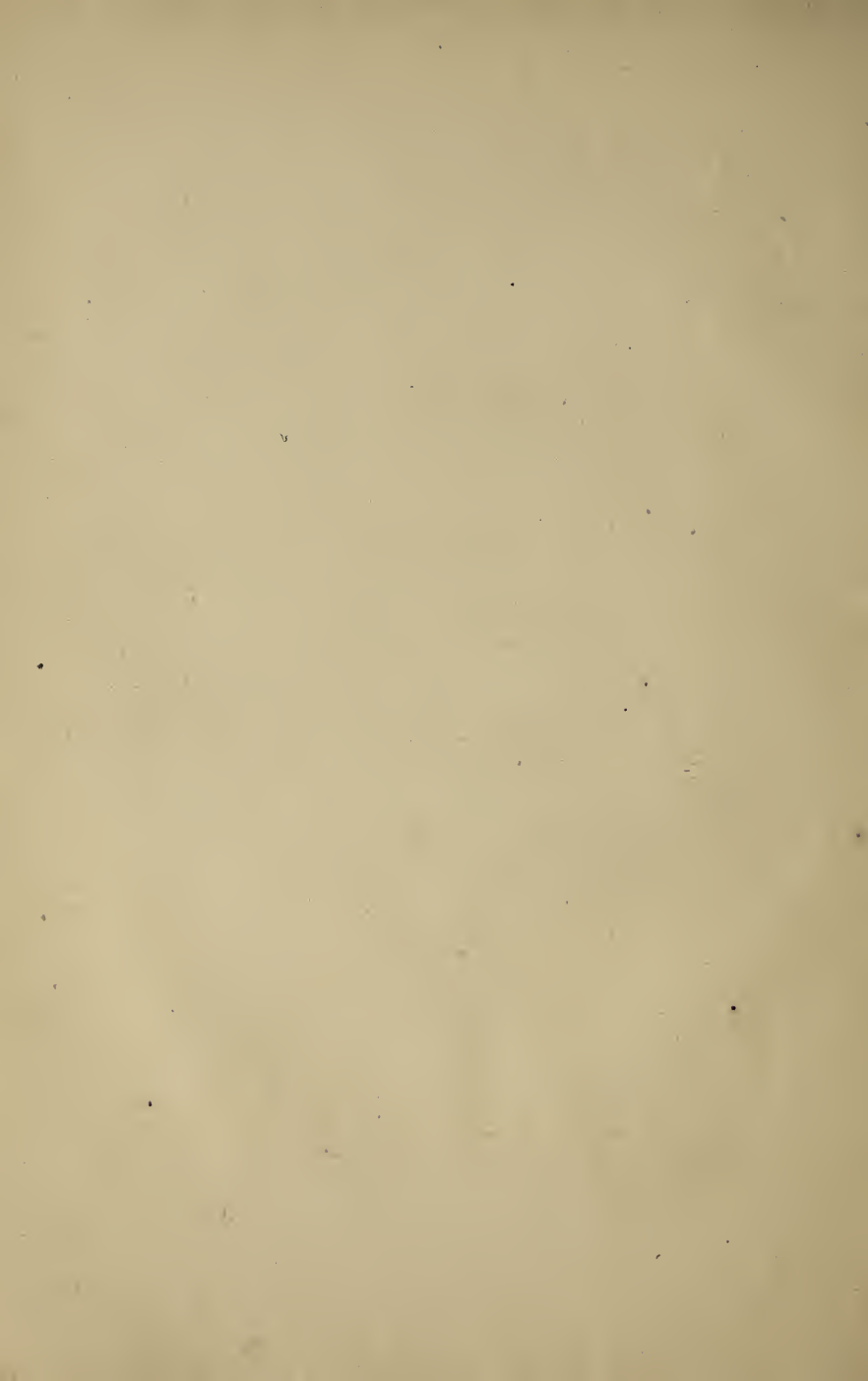
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PREFATORY NOTE.

The following pages contain lectures which have been delivered to the classes in Natural Philosophy for the past few years. They comprehend expositions of the later views respecting Matter and Force, and are published in order to afford the student better opportunities for thorough work. They will be read by the classes after completing the regular course in Physics, which is continued through the Sophomore and Junior years, and are to be supplemented by numerous experiments and additional matter.

J. K. M.

Physical Laboratory,
Agricultural College,
Ames, Iowa, Sept. 22d, 1876.



LECTURE I.

MOLECULES.

The word *molecule* means a little mass of matter. In physics, however, it has a definite meaning, and is the smallest portion of matter which can take part in any physical process. A *particle* is a group of molecules, as a grain of sand. Molecules are made up of *atoms*, which might be defined to be the smallest portions of matter which act in a chemical process. A particle of water, for example, is composed of molecules, each of which contains two atoms of hydrogen and one of oxygen gas. Until a comparatively recent date, matter was thought to be infinitely divisible. This notion arose from certain metaphysical speculations as to its constitution. To the mind, no particle is so small that it cannot be made smaller. For, however minute we conceive it to be it must have definite dimensions in three directions. It is necessarily a regular or irregular solid. It may be a sphere, cube, dodecahedron or some combination of these forms. In any case it must have an upper and an under side, a right and a left side, and a center. Mentally it can be divided into two parts and each of these into two more. The same argument will apply however far the subdivision be carried. In brief, the metaphysician settles the question by saying it is *inconceivable* that matter should not be infinitely divisible.

Conceive of a unit of matter which entirely fills the space within its periphery, without pores, and you get a notion of the chemist's atom; such an atom could not be divided. And with

due respect for the metaphysician's argument we are obliged to believe that matter is made up of indivisible atoms. We cannot directly prove this. We are too blunt in our perceptions to see them or handle them. We can conceive, however, that certain infinitesimal *demons*, as Sir W. Thomson calls them, might exist with senses so sharpened and actions so quick as to handle these atoms as men do billiard balls. And, if so, we may be sure that they would never break in pieces, however forcibly they were struck. Certain facts in chemistry indicate that all bodies are composed of solid indivisible atoms. The law of multiple proportions and others could be given as a proof of this. The atomic hypothesis; and, I will add the molecular hypothesis also, agree with the known laws of gases and the phenomena of gaseous bodies while all other hypotheses ignore them.

*The doctrine of Boscovich as to the constitution of matter was briefly as follows :

1. Matter has three dimensions.
2. Is impenetrable, and does not form a plenum.
3. Matter is made up of small, finite parts, of extreme hardness; unalterable by mechanical means, endowed with impenetrability and inertia. These ultimate parts are called *atoms*.
4. Atoms are not in mathematical contact, but are separated by distances which are great compared with the size of the atoms.
5. Between these atoms there are attractions and repulsions. If these forces are equal there is no change in the volume of the body.
6. These attractions and repulsions vary with the distance, in both direction and intensity. Hence, at one distance two atoms attract one another and at a different distance they repel, several changes of direction occurring within the range of physical contact, (about 1-2000th of an inch).
7. If the distance is increased, repulsion diminishes more

* Mayer's Lecture Notes on Physics, p. 90.

rapidly than attraction; if diminished, repulsion increases more rapidly than attraction.

8. The law for change of distance is constant for all atoms, and is mutual, since the distance from a to b is the same as from b to a .

9. Attraction acts at all distances over 1-2,000th of an inch varying inversely as the square of the distance.

10. As their distance diminishes the final acting force between two atoms is an insuperable repulsion. Hence no force can press two atoms into mathematical contact. With gases an indefinite repulsion exists.

11. The attractive and repulsive forces between the molecules of a liquid keep them at definite distances, but these forces act in no fixed direction. Hence a liquid possesses fluidity; its molecules rotate about any axis on the application of a slight force.

12. In solids there is *polarity*; the forces act in fixed directions, as do two magnets. Hence, when a molecule of a solid is disturbed, as by heat, it vibrates back and forth and after a few oscillations tends to resume its primitive position.

According to Sir William Thomson, "We may regard it as an established truth of science that a gas consists of moving molecules disturbed from rectilinear paths and constant velocities by collisions or mutual interferences, so rare that the mean length of proximately rectilinear portions of the path of each molecule is many times greater than the average distance from the center of each molecule to the center of the molecule nearest to it at any time. If, for a moment, we suppose the molecules to be hard, elastic globes all of one size, influencing one another only through actual contact, we have for each molecule simply a zigzag path composed of rectilinear portions with abrupt changes of direction." I give the above definition of a gas because it comes from one of the high priests of science. Gaseous molecules are continually darting hither and thither seeking to fly off indefinitely into space. One molecule on striking another is caused to rebound and move in a straight path until it

encounters a second, from which it is again repelled. If the pressure upon the gas decreases the volume increases, the rectilineal paths increase in length and the number of molecules in unit volume decreases. All are familiar with the fact that gases exert great pressures upon the surfaces which bound them. This pressure is due to the continual bombardment of the molecules against the surface, and for the atmosphere is equal to about fifteen pounds per square inch.

The molecules of all bodies are in a state of constant agitation. In the case of gases they make rapid and extensive excursions to and fro from one position to another. In liquids they are also free to move about in every direction, but the distance which any molecule can move before hitting another is small. Each molecule of a liquid must be regarded as continually darting about among its fellows jostling and being jostled incessantly. It is well known that if two liquids which can be mixed are placed in vessels in communication they will *diffuse* or mix completely, of their own accord, in a short time. This phenomenon will be readily understood from the foregoing. Allow me to illustrate. Conceive of two large rooms in communication by a wide door. Suppose these two rooms filled with people; in one room they are dressed in red and in the other in blue coats, and no one is supposed to care where he goes if he only keeps moving about. It is easy to see that the red and blue coats in the doorway will soon begin to collide. The blue coats will begin to move in among the red ones and the red coats to encroach upon the territory of those in blue. In a short time it is clear that the red and blue coats will be uniformly distributed through the two rooms. The same illustration will explain the diffusion of gases, only the free paths are immensely longer and the rapidity of diffusion much greater. In a solid the molecules retain the same relative positions, so that no diffusion takes place.

That the ultimate parts of a body are separated by considerable distances is to be inferred from several well known phenomena. All are aware of the fact that a cubic inch of water

makes a cubic foot of steam, or thereabouts. Now, is the steam homogeneous? Does every portion of the space contain its proportion of the vapor? Or, can we not conceive of spaces so small that they are empty. We will let experiments answer this question. Conceive of two glass globes impervious to air. In one there is air and the other is empty. Now, into the first drop as much water as will vaporize. Do the same for the empty globe. It is found that the one containing air takes up just as much vapor as the other. Now drop some alcohol into each. Just as much will vaporize in one as in the other. If ether is added the same thing occurs and, in general, we find that the vapors present seem not to hinder in the least the formation of others. Now how could this occur unless the particles of alcohol and ether occupy the spaces *between* the air particles? Again, it is found that each vapor exerts its own tension just as though it were alone. Now the pressures exerted by gases and vapors are due to the velocities of their molecules, hence each species preserves its individuality and also its own rate of vibration. The above experiments point to the conclusion that our gas is composed of distinct, separate, definite parts, constant in number, and consequently that gaseous bodies are not strictly homogeneous. If, then, we should consider very minute portions of space we could distinguish between vacuous portions and those occupied by the molecules.

It is supposed that the particles of the densest bodies are never in mathematical contact. But how can we determine this? Surely not by any of the coarser methods known to our senses. If we take the finest cambric needle and endeavor to find pores in a plate of polished glass we shall fail completely. Contiguous cubes of glass 1-1,000th of an inch in diameter would be as much alike as one brick wall is like another. But, as I shall show you, if we should consider cubes 1-250,000,000th of an inch in size we could probably distinguish between the molecules and the empty spaces. Just as, if from a brick wall we were to take a one-fourth inch cube it would most likely be either all mortar or all brick. Although no physical point can discover

these interstices, we find in light an agent capable of detecting them. A ray of light darts through the densest glass with far greater ease than water runs through a coarse sieve. With the undulatory theory of light you are already somewhat familiar. Light is propagated by means of a wave motion in an exceedingly tenuous medium called *ether* which surrounds the molecules of all bodies and penetrates all space to the uttermost bounds of the known universe. Now notice that it is not the *ether* which passes through the glass, but a *wave* in the ether. And the fact that light moves through the glass almost without hindrance indicates that the wave is very large compared with the size of the molecules.

But how large is a wave of light? For red light about 1-35,000th of an inch; for yellow, 1-40,000th and for violet light 1-60,000th of an inch. In other words, 40,000 waves of common white light could be placed end to end in an inch. These numbers appear very small but you must not think them impossible. The German optician Nobert rules such fine lines upon glass that 100,000 and over are placed side by side in the length of an inch. A soap bubble can be blown so thin that its thickness is less than one-fourth the length of a light-wave. When light traverses glass it is *refracted* and also *dispersed*. Now refraction is caused by retardation. And it was pointed out long ago by the French mathematician Cauchy that dispersion could only be accounted for by taking into account the size of the molecules in the refracting substance. The fact that light is so little dispersed indicates that a wave of light is very large compared with a molecule. But the fact that light is dispersed *at all* shows that the molecules are not infinitely small compared with a wave.

Dimensions of the Molecules of Matter.—The above considerations point to a method by means of which the size of the molecules can be inferred. The shortest wave would be most retarded and the longest the least so. Violet light having the shortest wave-length we would expect it to suffer the greatest retardation. We must regard the wave as a sieve through

which the molecules are sifted. Of course, the larger the meshes of the sieve, the more readily would the molecules pass. Shot would experience difficulty in falling through many sieves placed below one another, if the meshes were not much larger than the shot. But suppose these sieve-meshes were 10,000 times as large as the diameter of a shot, then the little bullets would fall through them with but slight hindrance. In the application of these illustrations to the case in hand we must not forget that the sieve moves among the shot and not the shot through the sieve.

According to Sir William Thomson, in the length of a wave of light there cannot be less than about 10,000 molecules of matter, or else there would be more dispersion than there actually is. In passing the distance of an inch, therefore, we would pass from a molecule to empty space 400,000,900 times; and 1-400,000,000th of an inch may be regarded as the mean distance between the centers of contiguous molecules. Of course this can only be regarded as a mere approximation; and were there not many other independent methods leading to results not far from this, we should deem it unworthy of mention here. From experiments based upon the *electricity of contact* of metals the same authority as given before arrives at 1-700,000,000th of an inch as the point at which we would reach the grained structure of matter. By still another method depending upon the amount of work required to pull out a soap bubble, about the number 1-500,000,000th of an inch has been arrived at as the mean distance between the centers of contiguous molecules of water. Still another process is based upon a mathematical proposition, proved by Clausius and Clerk Maxwell, *that the free path of a gaseous molecule, divided by its diameter, is equal to the ratio of the whole space occupied by the particles, to eight times the bulk of all the particles.* This is a mathematical result founded on the supposition that gaseous molecules are little, hard bodies constantly hitting one another. By *free path* is meant the average distance a molecule moves between successive collisions. We know the whole space occupied by a gas, and the bulk of all

the molecules can be approximated by supposing that in the liquid state they are nearly in contact. There are also methods of determining the *free path* with considerable accuracy, so that an equation can be formed giving the diameter of a particle in terms which have been approximately measured. This calculation has actually been made and the conclusion is reached that a molecule cannot be far from the 1-250,000,000th of an inch in effective diameter.*

Now if we take 1-500,000,000th of an inch, which is about the mean of the above results, and calculate the molecules in a given space, the number will be astonishing. In a cubic inch of a gas at the normal temperature and pressure there cannot be less than $125 \times (10)^{24}$ or, if we write it out, 125,000,000,000,000,000,000,000,000. Solids and liquids are from 500 to 16,000 times denser than air and would contain proportionately more molecules. An inch of water, for example, would have in it $6 \times (10)^{28}$, and in a single drop of water $(10)^{26}$, or a hundred million million million million. According to Gaudin, a pin's head cannot contain of chemical atoms less than the number represented by a figure eight followed by twenty-one ciphers!

Limit to the Magnifying Power of the Microscope.—These calculations respecting the size of molecules become of deep interest when compared with the probable limits to the magnifying power of the microscope. According to Helmholtz there is a limit to this power depending on the confusion of the image, and caused by the interference of light-waves. It is brought about by the interference bands overlapping the dark outlines of the object. And, according to this, †“light itself is of too coarse a nature to allow of our seeing minute objects distinctly defined.” This limit depends upon the wave-length of the light and for objectives having the largest apertures is reached when the diameter of the object equals about one-half the wave-length. We may assume 1-40,000th of an inch as the mean

* “*The Size of Atoms*,” Sir W. Thomson ; American Journal of Science, vol. L, p. 38.

† Mr. Sorby, “Nature,” Feb. 24th, 1876. “The relation between the powers of the microscope and the ultimate molecules of matter.”

length of a wave of white light, although for red light the number is about 1-35,000th and for violet 1-60,000th of an inch. This would give 1-80,000th of an inch as the theoretical limit of distinct visibility, which is said to agree with the mean of actual determinations of skillful microscopists. Nobert's lines ruled on glass containing 112,000 to the linear inch can be seen by high powers because by skillful manipulation the interference bands may be made to coincide with the ruled lines. The fact that lines less than 1-100,000th of an inch apart can be photographed is due to this, that the ultra-violet rays, which possess the highest photographic power, have a wave-length of less than 1-60,000th of an inch. Mr. Sorby concludes "that even with the very best lenses, except under special conditions, light itself is of too coarse a nature to enable us to define objects less than 1-80,000th to 1-100,000th of an inch apart according as a dry or immersion lens is used. We must also conclude that *as far as this question is concerned*, our microscopes have already reached this limit, whatever improvements remain to be made in other respects."

Taking the ultimate molecules to be the mean of the determinations of Thomson, Maxwell and others, that is, 1-500,000-000th of an inch, Mr. Sorby states that with the highest possible magnifying power the smallest interval definable would contain 2,000 molecules of water lying end to end, and 520 of albumen. The smallest visible speck would contain $(2,000)^3$, equal to 8,000-000,000 molecules of water, or 24,000,000,000 elementary atoms. In order to see elementary molecules our microscopes must magnify 2,000 to 500 times what they now do, and the wave length of light would have to be 1-2,000th its present dimensions if such instruments could be used. "As an illustration, I have calculated," remarks the same authority, "that with our highest powers we are as far from seeing the ultimate molecules of organic substances as we should be from seeing the contents of a newspaper at the distance of one-third of a mile; the larger and smaller types corresponding to the larger and smaller molecules of organic and inorganic constituents."

These considerations coming as they do from the president of

the Royal Microscopical Society of England are of considerable interest as pointing out to us in a forcible manner the limits to our knowledge. I desire, however, to call your attention to another matter which seems to me of even greater moment. I refer to the subject of *spontaneous generation* which is now agitating the scientific world. In order to get at this matter I have requested Professor Bessey to furnish me with a list of "little things," and he has kindly done so. The list is given below:

Diatom measurements.—*Pleurosigma batticum*, a large diatom from Brazil. Length from 1-39th to 1-42nd of an inch; greatest width, 1-438th of an inch. This specimen is marked by transverse striæ which are, according to Professor Morley, who recently measured them, 1-33,000th of an inch apart.

Navicula lyra, another diatom from Brazil; a familiar microscopic test object. Six specimens on my plate run, as follows: Length from 1-112th to 1-160th of an inch. Breadth, (at middle) 1-380th to 1-418th of an inch. The transverse striæ are from 15 to 25 on each 1-1,000th of an inch, *i. e.*: 1-15,000th to 1-25,000th of an inch apart.

Striatella unipunctata, is a short diatom like a round collar box. Diameter, 1-360th to 1-440th of an inch; length about the same.

Tabellaria fenestrata, another diatom. Length, 1-600th of an inch; breadth, 1-2,300th of an inch.

Amphipectura pellucida, the famous test diatom has its striæ 93 to 96 per 1-1,000th of an inch, *i. e.*, 1-93,000th to 1-96,000th of an inch apart.

Bastian speaks of *Bacteria* (low vegetable germs) which vary from 1-2,000th to 1-15,000th of an inch in length; they are rod-like organisms. He further, in "Beginnings of Life," p. 298, speaks of "faint and ill-defined specks less than 1-50,000th of an inch in diameter, some of which develop into *Bacteria*." The spores of some of our common moulds are spheres ranging from 1-6,000th to 1-9,000th an inch in diameter. The wood cells of the apple tree average about 1-1,800th of an inch in breadth, some being as large as 1-1,200th and others as small as

1-3,500th of an inch. The pollen grains of the golden currant are spherical and about 1-500th of an inch in diameter. In the protoplasm of their contents are found minute starch granules many of which are no more than 1-40,000th of an inch in diameter.

Now, in all experiments upon the subject of spontaneous generation it is assumed that living germs are absent unless they can be discovered by means of the microscope. Let us calculate the number of structural molecules which might be contained in some of these minute organisms. Take, for example, the smallest mentioned, "the faint and ill-defined speck less than 1-50,000th of an inch in diameter," which developed into a Bacterium. Using the common estimate, a 1-50,000th of an inch cube would contain 1,000,000,000,000 molecules of liquid water. Now the molecules which constitute organic bodies are much more complex than water and hence much larger. Assuming each structural molecule to consist of 100 equal to a molecule of water, and we would have of them in 1-50,000th of an inch 10,000,000,000. In other words, this minute "speck" just visible might be an exceedingly complicated organism. For we must regard these molecules as so many bricks used to build up the animal or vegetable germs. Now, a hundred thousand bricks will build a large house. Probably the Agricultural College Building does not contain more than two million bricks; but this minute "speck" contains a thousand times as many. In fact, according to the calculations of Sorby, a spherical particle one-tenth the diameter of the smallest speck which could be clearly defined by the highest powers, might contain no less than one million structural molecules!

Surely then it would be an error to assume that the invisibility of germs in an infusion proves their non-existence. If there be such a thing as spontaneous generation, it must begin, according to all analogy, with the lowest forms. These low forms would be composed of comparatively few molecules. Evolution in the organic world is at best a slow process, indeed, so slow is it, that it is denied to go on at all by many. Now we have no

reason to suppose that it goes on any more rapidly (relatively) among minute organisms than among large ones. Hence living germs may grow and multiply for years in solutions where the keen eye of the skilled microscopist fails to detect the slightest turbidity. It requires ages to progress from edifices containing a few hundred to those with as many million bricks. From the foregoing we may conclude that myriads of living organisms may exist too small ever to be seen by the highest powers of the microscope. There appears to be a world of "little things" as far beyond our microscopes as is the stellar world beyond the farthest sweep of the telescope. These investigations give us a notion of the way in which many malarial diseases may be propagated through the air from place to place. Professor Stokes has shown from calculations based upon the viscosity of air that a drop of water falling through air one thousand times rarer than itself, as in the higher regions of the atmosphere, would fall 8-10ths of an inch per second if it were the one-thousandth of an inch in diameter. Were its diameter but the ten-thousandth of an inch it would move one hundred times slower. In general, the particles of any substance are buoyed up in the inverse ratio of the square of their diameters, their density and form remaining unchanged. It is easy, from this, to see how minute spores from one-fifty-thousandth to one-hundred-thousandth of an inch in diameter could be supported for an indefinite time by the air and transported to great distances.

LECTURE II.

THE CONSTITUTION OF MATTER AND THE MOLECULAR THEORY OF GASES.

The Unity of Matter.—It is my intention to present in these lectures the latest views which have been advanced respecting matter and force. And it seems to me that anything like completeness will require a brief survey of the hypothesis which has been suggested recently as to the common nature of all matter. Surely at first such an idea seems absurd. It seems impossible to conceive that all the forms of matter are, after all, one and the same. We recognize in nature sixty-three elementary substances. In all chemical and physical processes they are assumed to remain unchanged. By no known force can the atoms of oxygen or hydrogen be simplified. And yet we must not be too hasty in our conclusions. At the commencement of the present century soda and potash were supposed to be simples. The genius of Davy showed them to be metallic oxides. Water was once thought to be an elementary substance but in 1800 Nicholson decomposed it by means of the voltaic battery and showed it to be composed of hydrogen and oxygen gases. We cannot affirm positively that oxygen gas is elementary. What we do know is that thus far it has resisted all attempts to simplify it. The same can be affirmed of all the chemical elements. And yet whether we examine them as atoms or as to their chemical relations we shall find many properties pointing to a common nature.

*There are few of the properties belonging to masses of matter which are common to the ultimate atoms. What is it, for example, that distinguishes an atom of hydrogen from one of oxygen? It cannot be a difference in density, solidity, hardness, porosity, fluidity, impenetrability, divisibility or sonorous properties. For, all these qualities depend upon the arrangement of atoms upon atoms; upon the disposition of atoms with respect to other atoms. Hence none of such properties can be attributed to a single atom. In what respect do they differ then? Simply in weight and magnitude. But this is not necessarily a qualitative, but a quantitative difference. It is not a difference in kind but of quantity. Sixteen atoms of hydrogen weigh *exactly* as much as one of oxygen. It is not impossible, therefore, that each oxygen atom is composed of sixteen atoms of hydrogen. Strange it is, indeed, that there should be no fractional difference in their weights. The difference between two atoms cannot be due to magnetic, electric, or heat properties, because these are, without much doubt, caused by movements of an ether which envelops the atoms. Clearly then, two heterogeneous atoms when compared, are by no means separated by so wide a chasm as are the groups of atoms known as masses of matter. The above demonstration is thought by some scientists to prove that primarily all matter is the same.

Many years ago it was pointed out by the eminent chemist Berthelot that the ultimate atoms of simple bodies might be composed of the same matter subject to vibrations of different natures. Let me illustrate. Here is a tuning fork which gives the middle C or 256 vibrations per second. I draw the bow across the prongs and you hear a rich swelling sound. I allow the sound to cease and again apply the bow. The same note is heard and however often the fork is caused to vibrate the identical sound is emitted. But here is another fork smaller than the first. I apply the bow and you hear a much higher note than before; in fact, it is the octave of the note given by the

* Papillon, "Nature and Life," p. 7.

larger fork and is produced by 512 vibrations per second. Now, both these forks are made of steel. And yet how they differ in their sonorous properties. Before you are two more steel forks which give notes of intermediate pitch. What would a blind man say was the cause of the difference in these sounds? Would he not ascribe it to a difference of substance? To us who can see the wide difference in the size of the forks the cause of the difference in pitch seems clear. Now I stick a penny to the prong of this fork. You see that the pitch is slightly altered. I remove the coin and warm the fork over this gas flame,—its pitch is altered again, so we see that the sound produced changes with every change in mass or elasticity. And yet it is a steel tuning fork all the time.

With respect to the atoms of matter we are somewhat in the condition of the blind man with reference to this tuning fork. Indeed, we are more in darkness than he. For the sense of touch would enable him to detect some of the causes of the difference of pitch, while we are forever precluded from either seeing or handling the atoms. It will be easy now for you to understand how the properties of atoms may depend upon motion. The fact that a so-called element (such as carbon, which occurs in the three forms of charcoal, graphite and the diamond) can appear in entirely different forms with wholly different physical properties goes far to remove the difficulties attending the hypothesis of the unity of matter. It is the aim of modern science to reduce all external agencies, whether matter or forces, to their lowest terms; to push the First Cause farther and farther back into the past, and to get as near as possible to the root of all things. All forces are correlated; may not the same be true of matter? Since we know nothing of force apart from matter, may not these two be correlated; possibly one and the same thing? But if all forms of matter are primarily identical, what do they spring from? Probably aggregations or nuclei of the universal ether, and, keeping in mind the fact that we are now treading upon speculative ground, I will leave this part of the subject by quoting a paragraph from Papillon:

“If the smallest parts which we can imagine and distinguish in bodies differ from each other only by the motions to which they are subjected, if motion alone rules and determines the variety of different attributes which characterize these atoms, if, in a word, the unity of matter exists—and it must exist—what is this fundamental and primary matter whence all the rest proceeds? How shall we represent it to our minds? Everything leads to the belief that it is not essentially distinguished from the ether, and consists in atoms of ether more or less strongly held together. It is objected that the ether is imponderable; but that is an unfounded objection. Doubtless it cannot be weighed; but to do that we must compare a space filled with ether with a space empty of ether; and we are evidently unable to isolate this subtile agent, whose particles counterpoise each other with perfect equilibrium throughout the universe. Yet many facts attest its prodigious elasticity. A flash of lightning is nothing more than a disturbance of equilibrium in the ether, yet no one will deny that lightning performs an immense work. However this may be, it is impossible to think of the energies that make up the atom otherwise than as pure force, and the ether itself, whose existence is demonstrated by the whole of physics, can be no otherwise defined than by the attributes of force. It follows from this that atoms, the last conclusion of chemistry, and ether, the last conclusion of physics, are substantially alike, although they form two distinct degrees, two unequal volumes, of the same original activity.”

I must now refer you to another class of facts pointing to the oneness of matter. It is well known that the so-called chemical elements are easily classified into natural groups. The members of these groups are alike in many respects. Take, for example, the group of which nitrogen is the type. Not only can these elements, nitrogen, phosphorus, arsenic, antimony and bismuth be arranged in regular series as to their atomic weights, chemical and physical properties, but the compounds which they form with other elements may be arranged in similar series. Such relations are not likely to be accidental. With the oxygen group an inter-

esting relation exists between their atomic weights; oxygen, 16; sulphur, 32; selenium, 79.5; tellurium, 128. Notice that the last three numbers are almost exact multiples of the first. Can this be due to chance? Of course it *proves* nothing. It simply points to a probable relation more profound than what we recognize upon a superficial view. Would time permit, many such series might be cited. The specific volume of a substance is the quotient arising from dividing its atomic weight by its specific gravity. For many of the groups of elementary atoms it is found that all the members have equal specific volumes. This rule applies to the iron and platinum groups. A singular relation is found to subsist between the specific volumes of the alkaline metals, lithium, sodium, potassium and rubidium. Their respective specific volumes are 11.9, 23.7, 45.1, and 56.2. The last three are very nearly multiples of the first number, and the deviation is much within the limits of experimental error. It is a well known fact in physics that the product of the atomic weights by the specific heats of the elements is a constant number, 6.4. Cases of allotropism and isomerism in which the same element or compound occurs in very diverse forms, are well known to chemists. The essential oils of rose, bergamot, orange, lemon, lavender, turpentine, rosemary, nutmeg, myrtle and peppermint are all composed of oxygen and hydrogen *in exactly the same proportions*. And yet how different is the odor of turpentine from that of lemon! A difference in the arrangement of the atoms in the complex molecule seems to produce these different properties.

Again, spectroscopic analysis points to the unity of matter. Especially is this view favored by the later examinations of the nebulae of the heavens. The inevitable conclusion seems to be that all the complex forms of matter have been evolved from simpler stock. As the penetrative power of telescopes is increased astronomers see more and more of those vast aggregations of incandescent gas known as nebulae. First, there is the simplest nebula of highly rarified hydrogen gas. Then can be described others still further advanced in the process of evolution, containing, besides hydrogen, calcium and perhaps magnesium. Others

appear still more complex in their spectra until we come to the sun whose atmosphere is known to contain a large number of elements. Finally we reach our own earth, which is far advanced in the process of evolution. Not only do we find evidences of evolution stamped upon the organic kingdom, but it also bears a part in the formation of the very stars and suns, and of the inorganic elements of the planet on which we live. Is it possible then, that, after all, all matter has been evolved from the same original germs? Surely such a consummation of our knowledge would be a noble one. Following hard upon the demonstration of the unity of force, the proof of the unity of matter would reduce the material world to two terms,—matter and force. Such a notion could not but elevate our ideas of the beauty of the universe and cause us to marvel at the mysterious power which works such wonders with so simple materials. Here let me warn you once more that we are treading upon speculative ground. And yet it is far from a baseless speculation. At present there are many seemingly insuperable obstacles to its realization. There is grand work in store for the scientists. To prove or disprove the doctrine of the unity of matter will demand the genius of many such men as Newton and Laplace.

Vortex atoms.—Within a recent date a new atomic hypothesis has been suggested by Sir William Thomson. I call it an “hypothesis” because on account of imperfect development it has not yet attained the dignity of a theory. Perhaps it never will be other than an hypothesis, but I feel assured that its novelty and importance warrant me in giving it a brief consideration here. All are more or less familiar with the beautiful curling wreaths of smoke occasionally emitted from the smoke stack of a locomotive. They frequently rise to a great height, preserving their symmetry for some time, finally to be dissipated in the surrounding air. Now these wreaths of smoke are exact representations of vortex atoms. But first let me show you some of them. Before you is a rude piece of apparatus with which I can produce as many as I choose without the trouble of watching the locomotive. It consists of a wooden box having a round hole in one end and a

sheet of India rubber stretched tightly over the end opposite. Now if I strike a quick blow upon the rubber a quantity of air will be forced from the aperture and assume the form of the hypothetical vortex atom. There will be a ring or circle of air in which the particles are all moving round very rapidly. Imagine a small hoop wound round and round many times with thread. The particles of air move in the direction of these threads around the rim of the hoop and each thread corresponds to the direction of the movement of an air particle. All this can be imagined but it will be much better if you can see it. I will pour some ammonia water into a capsule and place it in the box. Now I pour sulphuric acid over common salt in a porcelain dish and place it also inside the apparatus. See what a dense cloud of white smoke is generated! Sulphuric acid sets free the chlorine of the salt. This last combines with the escaping ammonia gas in the air and produces chloride of ammonia or sal ammoniac, which, as you know, is a white solid. I gently tap the rubber. See the beautiful vortex rings which issue from the orifice. Some of them move ten and even fifteen feet before they are destroyed by the friction of the air. Now I give the rubber a peculiar push and you see a wreath in which the rotary movement of the particles is plainly visible. Each ring is composed of innumerable particles of sal ammoniac and air, and after it has moved ten or more feet from the box, contains the same particles that it did on leaving the orifice. It can also be shown that a current of air is passing through the ring in the direction which it is moving.

The mathematical theory of vortex motion is very difficult and has been most thoroughly investigated by Helmholtz. These *vortex filaments*, as they are sometimes termed, are found to possess many wonderful properties. If air were a perfect fluid, a vortex filament once produced would exist forever. For, from the definition of a *perfect fluid*, there would be no friction. Nothing less than the power which creates could destroy such a ring once formed. Given a perfect fluid. Nothing short of creative power could generate therein a live vortex ring. And once let it exist, then that same extraneous energy must act in order

to annihilate it. Vortex rings are perfectly elastic. If two of them strike together they rebound as would two billiard balls. You cannot cut them with a knife or other instrument. For try in any way you choose they will wriggle around and escape unharmed. They are therefore indivisible. If one is following another with their axes in the same line, the one ahead expands and moves slower, while the other contracts and moves faster and finally it passes through the other. These rings may, theoretically, have any conceivable form with all sorts of knots and twistings. Now, Sir William Thomson suggests that what we call matter may be nothing but rotating portions of a perfect fluid which occupies all space. In other words, an atom is simply vortex motion. Every so-called atom is a vortex ring. Of course we cannot regard this hypothesis as of any value at present, although it promises to be a very fruitful one. The mathematical investigation of vortex motion is so difficult that it is only within the past fifteen years that anything of note has been accomplished, until it has finally yielded to the genius of the renowned German physicist Helmholtz. To such as wish to look further into the matter I take great pleasure in referring to the work of Professor Tait on "The Recent Advances in Physical Science," to which I am indebted for many of the foregoing suggestions.

Molecular Theory of Gases; Velocity of a Gas.—The theory of gases has been developed in a masterly manner by Professor Clerk Maxwell in his "Theory of Heat." To the thoughtful among you, who enjoy something more than a superficial view of the subject, many of his results will prove of great interest, and I shall therefore present, simplified as much as possible, the mathematical reasoning by which the more prominent laws are demonstrated.

The physicist is called upon to deal with the exceedingly minute in nature as well as the very large. At one moment he calculates the movements of a sun or planet millions of miles away and then he investigates with equal confidence the velocities of impinging atoms. Of one thing he feels sure. The same general principles which apply to one planet's action on another will also, with certain limitations, apply to the impact of two molecules. When

two particles of air strike together they act like two miniature billiard balls, and their motions can be predicted with equal certainty. It has been stated that the molecules of gaseous bodies are constantly in motion. Each individual has a motion of its own differing in direction and velocity from every other one. Respecting the motions of any one molecule we are in total ignorance, but such does not hold true respecting the *mean velocity* or *mean direction* of the molecules of the gas under consideration.

The pressure exerted by a gas upon the walls of a vessel will depend upon two quantities; first, its weight, and second, its velocity. And by its *velocity* we mean the mean rate of motion of its molecules. But how can this velocity be determined? At first glance it would seem to be a problem incapable of solution. If you will follow me carefully, however, I think you will admit it to be easier than it seems. Let us consider a cubic foot of hydrogen gas at the normal pressure and at zero degrees by the Centigrade thermometer. Its weight is 0.005592 pounds. Suppose this weight were moving as a single mass at the mean rate of its molecules, what momentum would it have? Or, suppose all the molecules turned about so as to move unobstructed in the same direction, how far would they go in one second? These questions we will now endeavor to answer. Assume that our cube of hydrogen has a uniform temperature in all its parts, and that its molecules have a uniform rate of motion. If we imagine this cube to be divided into two equal portions by a vertical plane, it is clear that molecules are continually passing from one side of it to the other. But, since the center of gravity of the gas does not change, as many molecules must pass in one direction as in the other. Conceive now of two other planes, at right angles to the first and also to one another, each dividing the cube into two equal portions. Now, in whatever direction the particles are moving, their motions can, by the principle of the parallelogram of forces, be resolved into three directions at right angles to these planes. Let n represent the number of molecules in a unit of volume. Let v represent their mean velocity resolved at right angles to one of the planes. Then the number of molecules which in a unit of

time will cross a unit of area from one side of the plane to the other will be nv . If m is the mass of a molecule the momentum of each will be mv , and the whole momentum transferred in a unit of time from one side of the plane to the other is,

$$(1) \quad mnv^2.$$

Now we know that this transfer of energy produces no motion of the gas; hence this momentum must be exerted as pressure against the walls of the cube. Since the vessel remains at rest, equal quantities of momentum must in equal times be transferred in both directions across the plane surface under consideration. And it must not be forgotten that the pressure upon the face of the cube will be due to two streams of molecules, those from it as well as toward it. From the above we may write,

$$(2) \quad p = mnv^2,$$

where p is the pressure exerted on a unit of area. Thus far we have considered motion in but one direction; if we consider motions in two other directions at right angles to the other two planes and represent the velocities resolved in these directions by w and x , we may write,

$$(3) \quad V^2 = v^2 + w^2 + x^2,$$

where V is the velocity without regard to direction, and V^2 the mean square of the three velocities at right angles to each other. In case our gas is at rest, $v^2 = w^2 = x^2$ or,

$$(4) \quad V^2 = 3v^2 \text{ and,}$$

$$(5) \quad p = \frac{mnV^2}{3},$$

by comparing equations (4) and (2), where n is the number of molecules in unit volume, m the mass of a single molecule and V^2 the mean square of the velocity. The mass of a single molecule has never been directly measured, nor has the number of molecules in a unit volume. In the above formula, however, we only consider their product, mn . This product of number by mass gives mass of unit volume which is the *density* of the gas, and the density of hydrogen gas is known. Therefore,

$$(6) \quad p = \frac{d V^2}{3},$$

where d is the density of the gas. From equation (6), by an obvious transformation, we get,

$$(7) \quad V = \sqrt{\frac{3p}{d}}.$$

In equation (7) we have all the data for calculating the velocity of a gas. Assuming the pressure to be 14.7 pounds per square inch, it would be 2116.8 pounds per square foot. At the melting point of ice and the above pressure the value of d for hydrogen gas is 0.005592 pounds per cubic foot. Hence $\frac{p}{d} = 378,540$ in gravitation units. Each gravitation unit equals 32.2 feet of acceleration. Multiplying the above number by three and by 32.2 and we have, $V^2 = 36,563,964$, and $V = 6,043$ feet, which is the velocity of the molecules of hydrogen gas at the normal pressure and temperature. This calculation was first made by Dr. Joule. A pound of hydrogen, then, contains as much energy as a pound of lead moving five times as fast as the swiftest bullet.

From the above formula the velocities of other gases may be readily calculated. Thus, for oxygen under normal conditions,

$$V = \sqrt{\frac{2,116.8}{.005592 \times 16}} = 1,512 \text{ feet,}$$

or one-fourth the velocity of hydrogen. This result might have been anticipated, since the energy of a moving body is proportional to the square of its velocity; and the density of oxygen is 16 times that of hydrogen. Therefore, their relative velocities would be inversely as the square roots of their densities, or, as 1 to 4.

Law of Avogadro.—Equal volumes of all substances when in the state of a gas, and under like conditions, contain the same number of molecules. The temperature of a gas measures its moving power or energy. It depends upon the actual *kinetic energy* of its molecules and is proportional to the quantity mv^2 , where m and v are respectively the mean mass and velocity of a molecule. When two gases have the same temperature, then, in all cases, $mv^2 = m'v'^2$. Whatever one of them lacks in weight it makes up in increased velocity. Assume, now, that we have equal volumes of each of two gases at the same temperature. Let m and m' , v and v' , represent their respective masses and veloci-

ties. Then to satisfy the conditions of thermal equilibrium we must have $mv^2 = m'v'^2$. Represent by p and p' the respective pressures exerted by the gases, and by n and n' the number of molecules in a unit volume. From equation (5) it is clear that

$$p = \frac{mnv^2}{3} \text{ and } p' = \frac{m'n'v'^2}{3}.$$

If the pressures are equal,

$$(8) \quad mnv^2 = m'n'v'^2.$$

Since their temperatures are the same,

$$(9) \quad mv^2 = m'v'^2.$$

Dividing equation (8) by (9) and we have,

$$(10) \quad \frac{mnv^2}{mv^2} = \frac{m'n'v'^2}{m'v'^2},$$

whence $n = n'$, which proves that the number of molecules in equal volumes of the two gases is the same.

If d and d' are the densities of our gases we have, $d = mn$; $d' = m'n'$. Whence the proportion,

$$d : d' :: m : m', \text{ since } n = n'.$$

Or, *the densities of gases are proportional to the masses of the individual molecules of which they are composed.* This is called the law of Gay Lussac and its application in the science of chemistry is of the highest theoretical and practical importance.

Absolute Temperature.—The coefficient of expansion of air is 1-273rd. Suppose we have a tube closed at one end, one square inch in cross section and two hundred and seventy-three inches long. Assume that the tube is filled with air at zero degrees Centigrade and the normal pressure. If heated to 1° it adds a cubic inch to its volume, and for each successive increment of one degree its volume increases one cubic inch. If its temperature falls one degree it loses an inch of volume, and at 273 degrees below zero it becomes, theoretically, nothing. Now it will be seen that by adding 273° to the ordinary reading of the Centigrade scale we have a point from which the volume of a gas is proportional to the temperature. Temperatures reckoned from this point are called *absolute*. When two gases are in thermal equilibrium, $mv^2 = m'v'^2$, and since the absolute temperature, as measured

by a gas thermometer, is proportional, for the first gas to v^2 , and for the second to v'^2 , and as v^2 and v'^2 are proportional, it follows that the absolute temperatures are proportional. Consequently, if they agree at one temperature, they agree throughout. This proves that, under similar conditions, all gases have the same coefficient of expansion.

LECTURE III.

THE CONSERVATION OF ENERGY.

Historical.—A hundred years ago the annihilation of matter was looked upon as an every day occurrence. The chemists of the last century, as well as the ancients, thought the invisibility of a substance ample proof of its non-existence. Combustion was destruction in the sense of absolute annihilation. When fuel was consumed it not only ceased to be fuel; it ceased to exist at all. Loss of weight did not necessarily mean loss of substance, nor did increase of weight imply an addition of matter. The invisible products so easily collected and quantitatively determined by the modern chemist were entirely lost sight of. The *phlogiston* theory served to explain all extraordinary phenomena. Phlogiston was assumed to be a form of matter which was *specifically light*. If added to a substance it decreased its weight and when subtracted from a body it made it heavier. When a metal rusts it gains in weight. Hence, says the modern chemist, it has combined with some substance. No, replies the chemist of a hundred years ago, it has only lost phlogiston. Cavendish thought it identical with hydrogen, while others considered phlogiston and light to be one and the same. During the latter part of the eighteenth century the French chemist Lavoisier gave the phlogiston theory its death blow. He introduced the use of balances and urged forcibly the importance of accurate quantitative analyses. Creation and destruction of matter are now known to lie beyond the domain of sci-

ence. The quantity of matter in the universe to-day is the same that it was in the beginning and will remain constant in quality and quantity for all time. We can only investigate change of form. Coal is consumed, but the ashes plus the gaseous products weigh exactly as much as the original specimen. We know that there is no alteration of the ultimate atoms in these transformations. Each atom of hydrogen or oxygen preserves its identity and its properties unharmed. In fact, the atom is truly an immortal being and the only one which is recognized by the scientist amidst all the infinite transmutations of the inorganic world.

Now, what is true of matter is true of force. And it is the statement of this great principle which is implied in the term *Conservation of Energy*. The natural forces with which we are acquainted might be thus tabulated:

LIGHT,
HEAT,
MAGNETISM,
ELECTRICITY,
GRAVITATION,
COHESION,
CHEMICAL AFFINITY.

To these might be added:

VITAL FORCE,
MIND.

Suppose we represent by a, b, c, d, e , etc., the total amount of force in the universe due to each of these respective agents, then the principle of the conservation is, that,

$$a + b + c + d + e +, \text{ etc.} = F,$$

F being a quantity having at all times the same numerical value. It is by no means to be understood that any one quantity in the first member of the above equation is constant in value, but that their *sum* will be always the same. For example, some of force a may be changed to b , or d may appear as e , but, if so, then we may be sure that b and e will gain the exact amounts lost by a and d .

Dim and vague notions respecting the true nature of matter and force may be found in the writings of more than two thousand years ago. The following is ascribed to Pythagoras, who lived about the year 600, B. C.: "Nothing perishes in this world, but things merely change their form. To be born means simply that a thing begins to be something different from what it was before; and dying is ceasing to be the same thing. *Yet, although nothing retains long the same image, the sum of the whole remains constant.*" It would not be easy for a modern philosopher to give more concisely the accepted views of force and matter; and yet, so far as we know, the statement of the ancient Grecian was a mere conjecture unsupported by experimental evidence.

In modern times, Joule, Regnault, Clausius, Helmholtz and Count Rumford are prominent among those who have contributed to the new theory of dynamics. The name of Dr. J. P. Joule will ever be connected with the subject of the mechanical equivalent of heat. By a series of laborious experiments extending through ten successive years, he proved that every unit of heat is equivalent to 1390 foot-pounds of mechanical energy. By this it is meant that the quantity of heat which will raise one pound of water through one degree C. will raise a one pound weight thirteen hundred and ninety feet high. If Fahrenheit degrees are used the number is 772. The accuracy of this number was confirmed in all possible ways, by experiments of the most refined nature, for Dr. Joule had received his training in the art of scientific investigation from John Dalton, the founder of the atomic theory of chemistry. Not only did he prove the principle by showing heat and work to be mutually convertible; but the generalization was extended to magnetic and electrical forces. He proved that an electric current which by its resistance in a conductor produces sufficient heat to raise one pound of water through one degree would decompose a quantity of water into free hydrogen and oxygen, which, when burned, would raise one pound of water one degree. It was further shown that this same quantity of electricity would develop

enough magnetic force to raise one pound 1390 feet high; thus establishing an exact quantitative relation between heat, electricity, magnetism and mechanical work. The same eminent experimenter arrived at the conclusion that a grain of coal burned in a steam engine would raise one pound 140 feet high, while the same weight of zinc consumed in a battery can only raise (theoretically) one pound 80 feet high. By comparing the cost of coal and zinc, he concluded that the expense of power by electro-magnetism would be twenty-five times that of steam.

The labors of our countryman, Benjamin Thompson, afterwards Count Rumford, are of special interest to Americans as having served largely to dispel the notion that heat was of a material nature. Having been employed by the Bavarian government at Munich in superintending the boring of some cannon, his attention was directed to the large quantity of heat produced and high temperature of the metallic chips separated by the borer. He proposed the following question:

“Whence comes the heat actually produced in the mechanical operation above mentioned? Is it furnished by the chips separated from the metal?”

Were this last the case then the thermal capacity of the chips would be less than that of the metal which had not been heated. Portions of the gun were sawed away and their capacities for heat examined. Rumford could detect no difference between the specific heat of the chips and of the unheated metal. A metallic cylinder was then designed for producing heat by friction. A flat bar of hardened steel was pressed against the bottom of the cylinder, and this last turned by horse power. At the beginning of the experiment the air and metal were at a temperature of 60° F. In half an hour the temperature of the metal was 130° and 837 grains of scaly material had been removed. The cylinder was now surrounded by a wooden box which was filled with water.

“The cylinder had been in motion but a short time,” says the experimenter, “when I perceived, by putting my hand into the water and touching the outside of the cylinder, that heat was

generated. At the end of an hour, the fluid, which weighed 18.77 pounds, or $2\frac{1}{2}$ gallons, had its temperature raised 47° , being now 107° Fahrenheit. In thirty minutes more, or one hour and a half after the machinery had been set in motion, the heat of the water was 142 degrees. At the end of two hours from the beginning, the temperature was 178 degrees. At two hours and thirty minutes it ACTUALLY BOILED!" "It would be difficult to describe the surprise and astonishment expressed in the countenances of the bystanders on seeing so large a quantity of water heated, and actually made to boil, without any fire. Though there was nothing that could be considered very surprising in this matter, yet I acknowledge fully that it afforded me a degree of childish pleasure which, were I ambitious of the reputation of a grave philosopher, I ought most certainly rather to hide than to discover." Rumford then calculated that sufficient heat had been generated to raise 26.58 lbs. of ice water to the boiling point. By calculation he showed that this heat was equal to that produced in burning $4\frac{1}{2}$ ounces of wax.

"From results of these computations," he concludes that, "the quantity of heat produced equably was greater than that due to the combustion of nine *wax candles*, each three-fourths of an inch in diameter, all burning together with clear bright flames. One horse would have been equal to the work performed, though two were actually employed. Heat may thus be produced merely by the strength of the horse, and, in case of necessity, this heat might be used in cooking victuals. But no circumstances could be imagined in which this method of procuring heat would be advantageous; for more heat might be obtained by using the fodder necessary for the support of the horse, as fuel."

From the above passage it appears that Count Rumford saw clearly the origin of VITAL FORCE and that *creation of force* does not take place in the living animal. "We have seen," says Rumford, "that a very considerable quantity of heat may be excited by the friction of two metallic surfaces, and given off in a constant stream or flux *in all directions* without interruption or intermission, and without any signs of diminution or exhaus-

tion. In reasoning on this circumstance we must not forget *that most remarkable circumstance*, that the source of the heat generated by friction in these experiments appeared evidently to be *inexhaustible*. It is hardly necessary to add, that anything which any *insulated* body or system of bodies can continue to furnish *without limitation* cannot possibly be a *material substance*; and it appears to be extremely difficult, if not quite impossible, to form any distinct idea of anything capable of being excited and communicated in these experiments, except it be MOTION."

"When the history of the dynamical theory of heat is written," says Dr. Tyndall, "the man who, in opposition to the scientific belief of his time, could experiment, and reason upon experiment, as Rumford did, cannot be lightly passed over. Hardly anything more powerful against the materiality of heat has been adduced; hardly anything more conclusive in the way of establishing that heat is what Rumford considered it to be, MOTION."*

Force; Energy; Work; Kinetic Energy.—Force, in physics, may be defined to be anything which produces motion, or which, in any way, modifies or changes the direction of motion. In some cases force may seem to destroy motion. Used in its broadest sense, a force is whatever produces or is capable of producing an *effect*. In a general way we speak of Physical forces, Chemical forces, Vital forces and Will force. In these four divisions all exhibitions of force may be classified. It is evident that there is a wide difference between them. What obvious relation or similarity is there between the force that impels a cannon ball and that which gives speed to the race-horse? And yet the first is an exhibition of physical force and the second of vital force. Or, again, consider the heat produced by the combustion of oxygen and hydrogen and discover, if you can, any connection between it and an act of the *will*. The first is due to chemical and the last to mental force. It will be one of the objects of these lectures

* "Heat as a Mode of Motion," Appendix to Lect. II.

to show that all force emanates primarily from the same source.

Before proceeding to consider the subject of kinetic energy it will be necessary to refresh your minds on the relation which force bears to work. The *momentum* of a moving body is a quantity which depends upon its mass and its velocity, and is measured by their product. If m represents the mass and v the velocity, then mv equals the momentum of the body under consideration. A moving body which gains in velocity is said to be *accelerated*, and the gain per second is called the *acceleration*. *When a force produces acceleration, or when it either produces or maintains motion in opposition to resistance, it is said to do* WORK. The quantity of work done depends on the amount of acceleration produced or the amount of resistance overcome. You are already acquainted with the unit of work. When a pound weight is raised a foot high in opposition to gravity a unit of work is done. If a laborer raises twenty pounds to the top of a scaffold twenty feet high, we say he has done four hundred units of work. Evidently he would do twice the work in raising the same weight forty feet high. Notice that the element of time does not enter into the calculation. We only take into account the number of pounds raised and the height of the scaffold, and are indifferent whether it has occupied days or weeks to perform the work. If, however, we consider the amount of work any given force is capable of doing, it is necessary to take into account the time it acts, since it is assumed that a force can do twice as much in two seconds as in one. Suppose we have a force which can do g units of work per second, and that it acts through h feet, then,

$$(1) \qquad w = gh,$$

where w is the work done; since a constant force is measured by the product of the force into the space through which it acts. Again, a constant force is measured by the momentum it can generate in a unit of time. If t is the time the force acts, v the initial and v' the final velocity of the mass m , then

$$(2) \qquad g = \frac{m(v' - v)}{t},$$

where g represents the force. The space passed over in time t , with initial velocity v and final velocity v' , will be the same as though the motion were uniform and equal to half the sum of v and v' , or,

$$(3) \quad h = \frac{(v' + v)t}{2},$$

since we are to regard a constant force as producing a uniform acceleration. Substituting (2) and (3) in (1) and we have,

$$w = \frac{m(v'^2 - v^2)}{2}.$$

If the initial velocity v equals 0, or, in other words, the body starts from a state of rest,

$$(4) \quad w = \frac{mv'^2}{2},$$

where v'^2 is the mean square of the velocity of the body under consideration. Equation (4) should be carefully remembered, as it will be frequently referred to hereafter. From it we can get the number of units of work which a body weighing m pounds and moving v feet per second is capable of doing when its motion is arrested. Equation (4) is said to measure the *living force, vis viva*, or KINETIC ENERGY of the body. The difference between momentum and kinetic energy should be clearly understood. The first is measured by the product mv and expresses the relation which a moving body bears to inertia. Kinetic energy is measured by $\frac{mv^2}{2}$ and measures the amount of work the body can do before its motion is arrested. The momentum of a railway train gives the amount of *useful* work done in a unit of time, while the kinetic energy is the *actual work* done against all resistances.

Laws of Motion.—1. *Action and reaction are always equal and in opposite directions.* Imagine a large solid globe of metal suspended in mid air and filled with people. However much the occupants of the sphere move about, it is clear that as a whole the system will remain at rest. Suppose that several of them attempt to start this metallic balloon by sitting on one

side and forcing a storm of wind against the opposite hemisphere by means of bellows. What would the prospect be for an aerial voyage? The powder which propels a Minie bullet with such tremendous velocity reacts with equal violence in a backward direction, as is frequently made manifest by the kick or recoil which the sportsman receives. If now we weigh the gun and multiply its weight by its velocity backward, it would exactly equal the product of the weight of the bullet by its velocity. In other words, the momenta would be equal. The heavier the ball compared with the weight of the gun the more severe the kick. We say a stone falls to the earth because of gravity, but the stone attracts the earth just as truly as the earth attracts the stone. If the earth be one million times larger than the stone, then the latter will move over one million times the space that the former does in their mutual coming together. A familiar illustration of the law of action and reaction is found in the case of a man in a boat who is exerting himself to the utmost to haul the boat ashore by a rope fastened to a post. Suppose, now, that another man, on shore, takes the rope from the post and begins to haul in on it. Will our boatman move any faster than in the first mentioned case? We leave the question for you to answer. It can be calculated from the law of inverse squares that in a second of time the moon falls towards the earth 0.0536 of an inch. The mass of the moon is about 1-80th that of the earth; hence, it can be shown that the latter falls toward the moon in each second a fraction of an inch represented by $0.0536 \div 80$, or 0.00067. If the moon should stop in its orbit it would fall to the earth; but the earth would also fall to the moon, and the distance of 240,000 miles which separates them would be traversed by the respective bodies in the inverse ratio of their masses.

Suppose a body a at rest is struck by another equal body b in motion; then a will move on with the velocity of b , while b comes to rest. If both are in motion and b overtakes and collides with a , it is found that a gains momentum and b loses an amount exactly equal. This consideration applies only to perfectly

elastic bodies, and it is evident that the sum of the momenta remains a constant quantity.

2. *A body at rest tends to remain at rest and a body in motion tends to move on forever, in a straight line, and uniformly.* This is the second law of motion and is called the *law of inertia*. Note that in the law there is implied the principle of the preservation of force. An oscillating pendulum in perfect vacuo tends to vibrate *forever*. Notice also that there is implied in the law the fact that no body possesses innate force. It must be acted upon by a force which is external, and in an active condition if it is put in motion.

Kinetic or Actual Energy.—We will now return to the example of the rifle bullet and see why it is so much more destructive in its effects than the mass of the gun, since, as we have seen, the momentum of the gun equals that of the bullet. The bullet deals out death and destruction in its course while the recoil is harmless. Evidently their effects are widely different. The momentum of a missile, it seems, does not measure its power to kill. For, if it did, the weapons of modern warfare would be alike destructive to friend and foe. Let us seek to discover the cause of this singular difference.

Suppose we consider a cannon weighing a ton which throws a 4 pound ball 1,000 feet per second. Then, since the momenta in opposite directions are equal,

$$4 \times 1,000 = 2,000 \times 2.$$

The cannon would roll backward 2 feet per second, and do no harm, while the 4 pound ball would be competent to destroy a score of men at the distance of a mile. Let us assume the effects proportional to the work done and see if we do not get a different result. Referring to formula (4), we have, work done by cannon equal to,

$$\frac{mv^2}{2} = \frac{2,000 \times (2)^2}{2} = 4,000 \text{ units.}$$

Work done by ball equal to,

$$\frac{mv^2}{2} = \frac{4 \times (1,000)^2}{2} = 2,000,000 \text{ units,}$$

or 500 times the effect of the gun! This is the key to the whole

matter. The fact is that the effect of a missile is proportional to the *square* of its velocity; is represented by the kinetic energy, which is given by one-half the product of the mass by the square of the velocity. This fact accounts for the terrible effects of railway disasters when trains are moving at high rates. A train running forty miles per hour possesses one hundred times the energy of another running four miles, and will do one hundred times the work in coming to rest. If it encounters an obstruction it will be smashed to pieces in the same ratio. The power required to move a train at different rates varies as the square of the velocity. This explains the difficulties attending the attainment of a very high speed. To move a train one hundred miles per hour would require twenty-five times the power it would to run it twenty miles in the same time. The coaches would need to be proportionally stronger and the wear of the rails would be immensely greater. It is a well known fact among artillerymen that an increase in the velocity of a projectile very much adds to its destructive power; double the velocity giving four times the penetrative capacity. In order to illustrate the superior virtue of modern projectiles with high velocities, suppose we have a battering ram weighing 4,000 pounds which moves against a wall 30 feet per second. Its kinetic energy will be,

$$\frac{mv^2}{2} = \frac{4,000 \times (30)^2}{2} = 1,800,000.$$

Its momentum will be,

$$mv = 4,000 \times 30 = 120,000.$$

A cannon ball weighing 50 pounds has a velocity of 1,200 feet per second. Its kinetic energy will be,

$$\frac{mv^2}{2} = \frac{50 \times (1,200)^2}{2} = 36,000,000.$$

Its momentum will be,

$$mv = 50 \times 1,200 = 60,000.$$

The battering ram has twice the momentum of the ball, but when we compare their kinetic energies they are as 20 to 1 in favor of the ball, and its destructive power in tearing down walls will be in this ratio when compared with the ram.

LECTURE IV.

POTENTIAL ENERGY—THEORY OF MACHINES.

In the preceding chapter the subject of kinetic energy or energy of motion has been considered. We must now study with some minuteness what is known as *potential energy*. And first allow me to recall to your minds the algebraic expressions which apply to freely falling bodies at the earth's surface. You will doubtless remember them. They are,

$$(1) \quad v = \sqrt{2gh}^* \text{ and,}$$

$$(2) \quad h = \frac{v^2}{2g},$$

where v is the velocity, h the height and g the accelerating force of gravity, or 32.2 feet. But what do these expressions tell us? From (1) we can get the final velocity a body would acquire in falling from a height h . By means of (2) we may determine the height to which a missile would rise if projected upward with an initial velocity v . Knowing the height in feet which the missile rises, it is evident that if we multiply this value by the weight in pounds m , we get the number of foot-pounds or units of work done; hence,

$$(3) \quad w = \frac{mv^2}{2g},$$

where w equals the work done by a mass m moving with a velocity v , for these formulæ are general, applying to projectiles as

* For the derivation of this expression, see Ganot's Physics (46).

well as to bodies acted on by gravity. Again, since for each 1390 units of work we have one unit of heat, if we divide this expression by the mechanical equivalent of heat, we get the number of units of heat produced when a projectile with mass m and velocity v is arrested suddenly in its course; hence,

$$(4) \quad \frac{mv^2}{2g \times 1390} = \text{units of heat produced.}$$

A thorough comprehension of these formulæ will make our work easy.

In the first second a falling body at the earth's surface traverses a space of 16.1 feet, and at the end of that time is moving at the rate of 32.2 feet per second. By this we mean that if it could move on uninfluenced by gravity for another second it would traverse a space of 32.2 feet. Now if we project a body upward with a velocity of 32.2 feet, it will rise 16.1 feet; for, from our formula,

$$h = \frac{v^2}{2g} = \frac{(32.2)^2}{2 \times 32.2} = 16.1.$$

Note the fact that in falling back to the earth it gains the original velocity it had when it started, and hence can do as much work as was required to raise it. We will now take a problem in connection with this matter and consider it in the light of the principle of the *conservation of energy*. A cannon ball weighing 100 pounds is projected vertically with a velocity of 1,000 feet per second:

1. How high will it rise?
2. What amount of work is done in lifting it?
3. How many units of heat are equivalent to the force of projection?
4. If caught and detained at its highest point, is the force which has been used to lift it lost?
5. Required the amount of heat produced by percussion, if it should fall to the earth.
6. Finally, could the ball have been raised in any way without the expenditure of force or doing of work? further, has there been any creation or loss of force?

By interrogating formula (1) we obtain the answer to the first question:

$$h = \frac{v^2}{2g} = \frac{(1000)^2}{64.4} = 15,543.4 + \text{ feet.}$$

Formula (3) answers our second question:

$$w = \frac{mv^2}{2g} = \frac{100 \times (1000)^2}{64.4} = 1,554,340 \text{ foot-pounds.}$$

From the fourth formula, we get,

$$\frac{mv^2}{2g \times 1390} = \frac{100 \times (1000)^2}{64.4 \times 1390} = 1,118.2 \text{ units of heat,}$$

as the equivalent of the mechanical energy required to throw a cannon ball of 100 pounds 15,543.4 feet high.

Now if at the top of its flight the ball be caught on a platform it will be seen that it is under entirely different conditions from what it was on the earth. It may be so placed on the support that the touch of the finger to a trigger will precipitate it to the earth a distance of nearly three miles. It evidently possesses a sort of latent power or capacity to do work which it did not possess before, and this fact is expressed by saying that it possesses **POTENTIAL ENERGY**, or energy in reserve. It is power to overcome resistance which is *stored up* ready for use at the will of the experimenter. Now is the force lost which raised the ball? Evidently not. Let us see. We know how much work it required to raise it, namely, 1,554,340 units. If it will do an equal amount in falling back to the earth, then we are in the condition we were when the experiment commenced and the world's energy has not been wasted.

From (1) we have

$$v = \sqrt{2gh} = \sqrt{(64.4 \times 15,543.4 +)} = 1,000.$$

From (4),

$$\frac{mv^2}{2g} = \frac{100 \times (1000)^2}{64.4} = 1,554,340 \text{ units of work.}$$

It is the same quantity as the one obtained before and we may regard it as a fixed principle that when work is done in raising a weight, the potential energy or energy of position acquired may be transmuted to an equal amount of kinetic energy. We may also be assured that if the ball had been allowed to roll

or slide back to its first position the heat produced by the friction would have equaled 1,118.2 units. If a man had carried it to the top of a mountain 15,543.4 feet high we may feel certain that an equivalent amount of force would have been used, furnished by the food which he had eaten. Our cannon ball hung by a rope over a pulley devoid of friction would, in falling, draw up another of equal weight, *i. e.* do 1,554,340 units of work.

In order to illustrate, suppose an army of men armed with javelins on a tower fifty feet high. Their adversaries are similarly armed and in all respects have equal strength and skill except that they are upon the earth fifty feet below. The result of the battle might be predicted beforehand. Every javelin hurled from the battlements possesses a potential energy of fifty units of force for each pound of weight, while each missile from below must lose an equal amount before reaching the point where it can do execution. It is evident that the besieged will soon demolish their assailants. A reservoir of water high up contains reserved or potential energy. It required force from the sun to raise the water into the reservoir. When it falls back into the sea an equivalent amount of energy will be changed from the potential to the kinetic form. A watch spring wound up is symbolic of potential energy. A large amount of force is required a short time to wind it, and this is held in reserve by the ingenious mechanism, to be used only in just such minute installments as are required to keep the little wheels in motion. A loaded rifle or cannon contains a large amount of this form of energy. Cock the rifle, touch the trigger and its energy becomes kinetic.

Fuel, such as wood, coal, oil, etc., are other examples of reserved energy. A man of great wealth possesses a vast accumulation of reserved or potential energy. The energy of the laborer, or the man who depends for his support on the immediate and constant exertion of muscle or brain, possesses only active or kinetic energy. When the rich man pays from his hoard a laborer for his services we have energy of potential changed to that which is kinetic. In the light of the preceeding I need not tell you that the potential form of energy is most desirable. The

energy of the cannon ball is not lost, but, as you will see hereafter, it is wasted. It cannot last. Reserved as energy of potential it might be used to drive a hundred watches for a century. It has been compared to a profligate young heir who rushes forth in the morning with millions at his command, but who squanders his suddenly acquired possessions in a day.

Theory of Machines.—Machines create no force. It is the province of machinery to transmit, transmute and change the direction of motion but not to generate it. By the use of pulleys, levers, inclined planes and screws, force may be changed in direction, modified in quantity and a small power may raise a heavy weight *by allowing sufficient time for it to act*. A machine adapts the power to the resistance. Given a great weight and small power; it enables us to raise the weight by applying the power a sufficient length of time. For it must be remembered that in calculating the work a given power can accomplish we must always take into account the *time* which it *acts*, or the *space* which it traverses. Again, a motion in one direction may be used to propel a weight in another, by means of a machine. We shall now take up the simple mechanical powers and explain their use and mode of action. In what follows, *p* stands for power, *w* for weight, *f* for fulcrum, and the motion is supposed to take place in a vertical plane.

The Lever.—Suppose a stone weighing 100 lbs. is to be raised by a lever of the first class. Assume the lever six feet long and the fulcrum one foot from the stone. Then, from the conditions of equilibrium, we would have,

$$\begin{aligned} p : w &:: wf : pf, \\ &:: 1 : 5. \end{aligned}$$

Since *w* equals 100, *p* equals 20. Now the two arms of the lever in revolving about the fulcrum generate in their extreme position two triangles whose vertical angles are equal. From these triangles it can be proved that if *w* is lifted one foot *p* must fall five feet. Now what does this mean? Have we created any force in this? Have we stolen a march on nature and added to the sum total of the energy in the universe? Not at all. After

w has been lifted we have 100 pounds 1 foot high or 100 units of potential energy *more* than before. But glance at the state of things on the other side of the fulcrum. There, 20 pounds have fallen through 5 feet which amounts to a *loss* of 100 units of potential energy. I think you will admit that nothing is gained from nature in this system.

Pulleys.—In the simple pulley a cord hanging over a grooved wheel has the weight on one side and the power on the other. Since the two radii of the pulley are equal, the axis may be regarded as a fulcrum and we have a case of the lever in which wf and pf are equal. Under these circumstances the power equals the weight. If p falls, w rises an equal amount. In every system of compound pulleys it can be shown that whatever potential energy the weight gains in rising the power loses in falling. For example, where there are three movable pulleys and a single rope we have,

$$p : w :: 1 : 2n,$$

where n is the number of movable pulleys.

Hence, in the case supposed:

$$p : w :: 1 : 6.$$

Now, it can be shown that in every instance, if w rises 1 foot p falls 6 feet; that is, p loses the exact amount of potential energy which w gains.

Let us pass to the *inclined plane*. Represent its length by l and its height by h . Then, by the conditions of equilibrium,

$$p : w :: h : l.$$

$$pl = wh.$$

By a little consideration you will see that if w is elevated to the vertical height h , p must fall a vertical distance of l . Whatever is gained of potential energy by the weight is lost by the power. In general, *the small weight multiplied by the distance through which it is lowered exactly equals the product of the large weight into the amount it is raised*. This is called the principle of virtual velocities and was first discovered and announced by Galileo. The wedge and the screw I need not mention since they are particular cases of the inclined plane. I think

all who have followed me closely will see that a machine is not a creator of force. The principle of the lever has been known so long that we have no record of the discoverer. Archimedes stated that with a fulcrum and a place on which to stand he could shake the world. A Frenchman has taken the pains to calculate that it would require forty millions of centuries for him to move it the breadth of a single hair. **WHATEVER IS GAINED IN POWER IS LOST IN TIME OR VELOCITY.** This is called the golden rule of mechanics.

Apparent loss of Energy; Conversion into Heat.—No machine can supply of available force as much as is expended to put it in motion. In fact the quantities dealt with thus far are purely theoretical. They are not the values obtained in practical experience. A missile projected upward with a velocity of 32.2 feet will not *quite* attain a height of 16.1 feet. The ratio of the power to the weight must be a little greater than that pointed out by theory. No steam engine can ever give in actual work as much energy as is really represented by the fuel that it burns. No reservoir of water, however favorable its position or however well constructed the wheels by which it is applied, can ever give back in good honest work as much as theory indicates that it should. No bended bow will expend all its potential energy in driving the arrow into the target. Neither will a watch spring devote all its reserve energy to driving its scheme of wheels. Everywhere in nature there seems to be a waste of force which is unaccountable. To use a rather violent figure, there appear to be innumerable leaks in Nature's great steam boiler by which force is continually escaping without doing the work which the engineer designed that it should. And now we will seek for some of these leaks. I do not promise to stop them. We cannot plug up the holes and prevent the steam from escaping. We cannot even direct it to channels by which it may be made available. What we know is that there is a loose joint somewhere and it must be found. "Oh, yes," I hear some one say, "you propose to give us a dissertation upon friction." You have hit it exactly. For, from friction arises this loss of energy previously mentioned.

In proportion as we are made acquainted with the natural forces it becomes more and more evident that they are but different forms of motion. Heat was once assumed to be matter. It is now universally admitted to be molecular motion. Its analogy to and ready convertibility into light indicate it to be an exhibition of molecular energy. The fact that heat, *molecular motion*, can be made to produce *mass motion*, as when hot steam moves the piston of an engine, points forcibly to the same conclusion. The energy which disappears on account of friction is converted into heat. A portion of the energy of a motor goes to produce a mass motion which we name sound. Not a little is changed to electrical energy, and still more is used up in the performance of interior work, *i. e.*, changing the positions of molecules. All these quantities are insignificant, however, compared with that which seems to be annihilated by friction. It is the constant problem of the machinist to diminish this quantity as much as possible. The axles of car wheels become so heated by friction that frequently the oil upon them takes fire. Apply the iron brake and the entire moving force of a railway train can be converted into heat. Frequently a stream of fiery sparks will pour from the wheels. Lubricators and oils are used to lessen this friction and allow the power to be applied to its legitimate purpose of driving the train.

Now if it can be shown that each unit of force has its invariable equivalent of heat where that heat *seems* to be annihilated by friction, we shall have taken a long stride in the direction we are tending. This proof has, as you already know, been furnished by Dr. Joule and Professor Mayer. By a series of very exact and laborious experiments he has shown that by taking the proper precautions the heat of friction can in every case be collected and measured. On the other hand, Rankine, Clausius and Thomson have shown that every unit of heat may with proper precautions be made to perform its equivalent of work. This shows that heat and work are not only mutually convertible, but that they cannot be lost. Given 1390 units of potential energy, and it will produce in every instance its

equivalent of heat. On the other hand, given a unit of heat; it may be made to perform its equivalent of work. The principle of the *conservation of energy* may be now considered as established. Motion is never lost. It simply changes its form. It cannot be destroyed in the sense of annihilation any more than can a molecule of hydrogen. Whether we recognize it as light from a distant star, as heat from the furnace, as the energy of the cannon ball or the onward rush of a passing train, we may rest assured that in some form or other it will exist forever. The conditions under which it may be observed are almost infinite. It may rise in the heated vapor of the air to appear as a tornado which carries destruction in its course, only to dart again from a cloud as a sheet of lightning followed by the roll of the thunder. Again, this same wonderful force which has successively appeared as upward motion, the tornado, lightning and thunder, may appear as attractive force in a magnet, may become vital force in a plant, or supply the power which drives the quill in the penning of a poem.

LECTURE V.

CONVERTIBILITY OF THE NATURAL FORCES.

Light.—Sir Isaac Newton conceived light to be due to infinitesimal particles of matter which were shot forth continually from luminous bodies. These corpuscles moved at the rate of 185,000 miles per second and impinging upon the retina of the eye produced the visual sensation. We know that the visual impression persists from 1-10th to 1-5th of a second; therefore, if from five to ten corpuscles per second entered the eye they would produce continuous vision. From the velocity of light it is easy to calculate that a line of these particles 20,000 miles apart would

NOTE.—The Undulatory Theory of Light is perhaps the best example of a perfect theory with which we are acquainted. There is no established independent evidence of the existence of the luminiferous ether, and yet the physicist talks about it with as much confidence as he does of air-waves in studying the phenomena of sound. An hypothesis which enables us to explain all known phenomena, and finally to predict new consequences, becomes a theory. Of all theories this one has been most prolific of grand results. It has withstood the criticisms of the greatest minds. Among the many instances in which the wave theory has led to the discovery of new phenomena only one will be mentioned. While engaged in a mathematical investigation respecting the passage of light through certain crystals, Sir W. R. Hamilton found that Fresnel had misinterpreted his formulæ and that, rightly understood, they pointed to phenomena of a kind never witnessed. When a pencil of light penetrates a biaxial crystal in a certain direction it does not pass through as a single pencil, but is broken up into an infinite number of rays which produce a cone of light in the crystal and emerge as a hollow cylinder. Now cones and cylinders of light are unknown in any other case, so that the phenomenon may be regarded as entirely wanting in analogy. Mr. Hamilton predicted these

serve to give this sensation. On this hypothesis, the different colored lights were supposed to be due to corpuscles of different sizes. Red light, for example, was referred to very coarse, and violet to very fine corpuscles. The corpuscular theory was upheld for some time through the powerful support of Newton, but is now entirely superseded by the undulatory theory, which has been developed by the genius of Huyghens, Young, Euler and Fresnel.

There can be no reasonable doubt that light and heat are manifestations of the same force. Undulations of the etherial medium are known to produce directly light, heat, and chemical action. Pass white light through a prism and it is decomposed into an infinite number of colors, which may be caught upon a screen. That which is visible is known as the luminous spectrum; beyond the red is a thermal spectrum, and beyond the results from purely theoretical considerations based on the undulatory theory. He suggested to a friend, Mr. Lloyd, an optician, to test the result by experiment. He did so and the mathematical predictions were completely verified, thus establishing beyond the shadow of a doubt the greatest theory known to science.

We cannot ignore the fact, however, that there are grave objections to this theory, and that we are compelled to assume a combination of qualities in the ether which is inconceivable. The velocity with which wave motion is transmitted is proportional to the square root of the elasticity of the medium divided by its density. "Assuming that two media have the same density, their elasticities are proportional to the squares of the velocities with which a wave travels. The velocity of the sound-wave in air is about 1,100 feet per second, or one-fifth of a mile, that of light about 185,000 miles a second, or nearly one million times greater; and, if we take into account certain causes, which, though they tend to increase the velocity of sound, can have no effect on the luminiferous ether, the difference would be even greater than this. Now, were the density of the ether as great as that of the atmosphere, (say one-third of a grain per cubic inch,) its elasticity or power of resisting pressure would be a million square, or a million million times that of the atmosphere. But, as you well know, the atmosphere can resist a pressure of about fifteen pounds to the square inch; hence the ether, when equally dense, would resist a pressure of fifteen million million pounds to the square inch, or, making the correction referred to above, seventeen million million pounds to the square inch. Of course, such numbers convey no impression except that of vast magnitude; and you will obtain a clearer idea of the power when I tell you that

violet are the actinic rays. Among the luminous, are heat rays; and, in fact, every light ray may be regarded as also a heat ray. Actual experiments indicate that the ultra red, and violet rays differ in wave-length by about an *octave*; that is, the red waves are twice as long as the violet. Below is a table of actual measurements as given by Professor Cooke:

SIZE OF LIGHT-WAVES.

COLORS.	NO. OF WAVES IN ONE INCH.	NO. OF OSCILLATIONS IN ONE SECOND.
Red.....	39,000	477,000,000,000,000
Orange.....	42,000	596,000,000,000,000
Yellow.....	44,000	535,000,000,000,000
Green.....	47,000	577,000,000,000,000
Blue.....	51,000	622,000,000,000,000
Indigo.....	54,000	658,000,000,000,000
Violet.....	57,000	699,000,000,000,000

From the table it appears that the red wave is not quite twice the violet, but this is due to the fact that the measurements do this pressure is about the weight of a cubic mile of granite rock.”—*Cooke’s New Chemistry*, p. 22.

“We are asked by physical philosophers to give up all our ordinary prepossessions, and believe that the interstellar space which seemed so empty is not empty at all, but filled with something immensely more solid and elastic than steel. As Dr. Young himself remarked, ‘the luminiferous ether, pervading all space, and penetrating almost all substances, is not only highly elastic but absolutely solid!!!’ Sir John Herschel has calculated the amount of force which may be supposed, according to the undulatory theory of light, to be exerted at each point in space, and finds it to be 1,148,000,000,000 times the elastic force of the air at the earth’s surface, so that the pressure of the ether upon a square inch of surface must be about 17,000,000,000,000, or seventeen trillions of pounds. Yet we live and move without appreciable resistance through this medium, infinitely harder and more elastic than adamant. All our ordinary notions must be laid aside in contemplating such an hypothesis; yet they are no more than the observed phenomena of light and heat force us to accept. We cannot deny even the strange suggestion of Dr. Young that there may be independent worlds, some possibly existing in different parts of space, but others perhaps pervading each other unseen and unknown in the same space. For if we are bound to admit the conception of this adamantine firmament, it is equally easy to admit a plurality of such. We see, then, that mere difficulties of conception must not, in the least, discredit a theory which otherwise agrees with facts, and we must only reject hypotheses which are inconceivable in the sense of breaking distinctly the primary laws of thought and nature.”—*Jevons’ Principles of Science*, Vol. II., p. 145.

not correspond to the ultra red or violet rays, but to rays at a short distance from the two extremities of the luminous spectrum. Were it possible to make measurements, we may assume it highly probable, from analogy, that the following dimensions, or thereabouts, would be found for wave-lengths corresponding to the spectrum from a rock salt prism:

PROBABLE DIMENSIONS OF THERMAL, LUMINOUS AND ACTINIC WAVES.

POSITION OF WAVE.	NO. OF WAVES IN ONE INCH.	NO. OF OSCILLATIONS IN ONE SECOND.
Ultra heat wave.....	17,500	203,728,000,000,000
Ultra red wave.....	35,000	407,456,000,000,000
Ultra violet wave.....	70,000	814,912,000,000,000
Ultra actinic wave.....	140,000	1,629,824,000,000,000

I say prism of *rock salt* because, as you are already aware, it is the only substance which permits undulations of all dimensions to pass freely. Now the above measurements have not all of them ever been directly made, but we have the best of reasons for believing that the dimensions corresponding to them actually exist. But what do they mean? Simply this: Undulations of the etherial medium from 1-17,500th to 1-35,000th of an inch produce effects known only as *heat*; those between 1-35,000th and 1-70,000th produce both luminous and thermal effects; while all of a shorter wave-length than 1-70,000th of an inch are known only by their tendency to produce chemical combinations. The long undulations falling on the back of the hand, for example, produce pain; in other words, they disorganize the tissues. Undulations of intermediate lengths falling on the nerve of the eye are the cause of vision, while the rapid oscillations of the short waves bring the molecules of different substances in such close contact, with such force, that they are shivered to pieces, decomposed, and made to enter into new combinations. Clearly, then, these three phenomena are but manifestations of the same force. That they are due to impulses, wave motions, which are the same in kind but differ in intensity and in the capacity to produce special effects, seems the inevitable conclusion. They are secondary causes, of which the etherial impulse is primary, and are evidently correlated,

When light is absorbed it is converted into heat. Obscure thermal rays may be made to produce light as has been shown by Professor Tyndall. Professor Grove has by means of an ingenious experiment been able to get from the ultra-violet rays heat, electricity, magnetism and mass motion.

“A Daguerreotype plate prepared to receive an image is placed in a box filled with water having a glass front with a shutter over it. Between this glass and the plate is a gridiron of silver wire. The plate is connected with one end of a galvanometer wire, and the gridiron of wire with one extremity of a Breguet’s helix—an instrument formed of two metals coiled together so as to indicate minute changes of temperature. The other end of the helix is connected to the galvanometer wire and the needle brought to zero. As soon as either a beam of daylight or the oxyhydrogen light is, by raising the shutter, admitted so as to impinge upon the plate, the needle is deflected.” Light is the initial force. It decomposes the iodide of silver on the sensitive plate. Chemical action generates electricity, which passes through the wire. The wire is heated by the electricity, as indicated by the helix; magnetism is induced in the coil and *motion* in the needle. The chemical effects of light have even been investigated by means of the electric current produced.

Heat.—Heat is a form of motion. A hot body is one whose molecules are in rapid vibration. It is so easily converted into mass motion that no extensive proof as to its nature is necessary. For example, the chemical union of the coal and oxygen in the furnace of a locomotive is the initial cause of the motion of the train. Briefly follow me while I trace out this transmutation from atomic to mass motion. First, the atoms of carbon and oxygen have a powerful affinity for one another. At ordinary temperatures, however, this attraction is too weak to overcome the molecular repulsion between the particles. A match must be used to start the combination. Once let the atoms get in such proximity that the atomic attraction exceeds the molecular repulsion and the particles dart across the intervening space with such tremendous velocity that the surrounding ether is shivered

into impulses or waves known to us as heat. The shock of the meeting atoms springing across indefinitely small spaces is the primary and initial cause. These atoms live in a medium which shakes and quivers like a jelly. Its motion is transmitted to the solid molecules of the iron boiler. Again must this last transfer its atomic vibrations to the water. The water shivers to pieces; the molecular attraction is superseded by a repulsive force, and here is our *steam* which is accorded the honor of driving the machinery. But not yet is the motion available. The infinitesimal molecules of steam beat vigorously upon the piston and in its back and forth movement we find our first *mass motion*.

At first it seems astonishing that the few ounces of steam behind a piston should act with such tremendous energy. How, for example, can a few ounces exert a pressure of 12,000 pounds upon a piston as is frequently the case in the cylinder of a locomotive? The pressure of any separate particle will depend upon two things, its weight and its velocity. As you are already aware, the velocities of several gases have been calculated with considerable certainty. Now the pressure will also depend upon the number of molecules per unit volume. This number is enormous, being not less than $(10)^{24}$, or 1,000,000,000,000,000,000,000,000 per cubic inch of any gas at the normal pressure and 0° . The velocity of a molecule of hydrogen at zero and a pressure of 30 inches is over 6,000 feet per second, or five times that of a rifle bullet. Hence, one pound of hydrogen under the above conditions contains as much energy as a pound of lead moving 6,000 feet per second. As the temperature of steam rises, the velocity increases and it will be easy to believe that these enormous velocities can produce the great pressures observed.

Chemical Affinity.—How are we to regard the force of chemical affinity? It is the source of all our artificial light and heat, and it is well worth our while to examine as to its origin and its ultimate end. All separated particles in the universe which have an affinity for one another are in a state of potential energy. They resemble a weight, raised high above the earth, ready at any moment to drop and have its potential energy become ki-

netic. In the beginning, these atoms of matter seem to have been separated from those for which they have an affinity. Under certain conditions they combine, and once locked in mutual embrace they can never be torn asunder unless an amount of force equal to that which they produced in combining is used up as work. Free oxygen and carbon are, with reference to one another, in a state of potential energy. When they unite to form carbonic oxide, CO , a certain amount of heat is set free; this gas burns and takes up another molecule of O and becomes CO_2 , or carbonic acid gas, when an additional quantity of heat is set free. The potential energy is now kinetic. Carbonic acid is a very stable compound and can only be decomposed at great expense of force. The weight has fallen. The watch has run down. In some way it must be wound up, if the work of measuring time goes on. It is a well known fact that, at a very high temperature, water is decomposed into its elements oxygen and hydrogen. These elements in recombining produce great heat, and it was thought by some, when the fact was first discovered, that more heat could be produced by the combination of these free gases than was necessary to separate them, and that the excess could be utilized for driving machinery. Surely, thought the practical men, we have the advantage of Nature here and will get up a perpetual motion in spite of the old dame. The feasibility of such a plan becomes a vanishing point when considered in the light of the principle of the conservation of energy. Precisely as much force would be required to decompose the water as would be produced by the combination of the separated gases, and nothing would remain for practical purposes.

Electricity.—Electricity is one of the natural forces which is known by attractions, repulsions, heating, luminous, chemical and mechanical effects. It is usually excited by either friction or chemical action, and the quantity of electrical energy excited invariably depends upon the amount of mechanical energy exerted, or the weight of zinc or other substance dissolved by the acid. Given an electrified conductor. It may be used to excite an indefinite amount of electricity on other conductors, simply

by causing them to approach and recede from it. Let me illustrate. Here is a conductor charged with positive electricity. I move up within a few inches of it another conductor in the neutral state. Now, what is the condition of the electric fluid on it? You know that it is separated, the positive electricity being repelled and the negative attracted to the portion nearest the charged conductor. I move it away, the electricities combine and resume their former condition. But suppose that while the second conductor is near the first I touch it with my finger. There, a spark passed, and now, by removing the second conductor away, I find it is electrified. I have accumulated a store of energy in the above operation. If I do the same thing with five hundred conductors, I can charge them all, and in this way accumulate a large amount of electrical energy. Have I added to the world's stock of force in this process? Each time that a conductor is drawn away from the first one it is evidently moved in opposition to an attracting force. I must use force to separate the two conductors; in other words, I do work, and this work appears as the potential energy of separated electricities.

In the development of electricity by friction, work—mechanical energy—reappears as electrical energy. And the amount of electricity excited measures the work done. The electrophorus and friction machine are both included in this explanation. In the case of the Holtz induction machine, a small quantity of free electricity excited by friction serves to separate an indefinite amount in adjacent conductors; but the mechanical energy needed to turn the revolving plate is an exact equivalent of the generated electrical energy. Any one who has turned the plate of a Holtz machine knows that more force is required when electricity is generated than when it is not.

The law of Lenz rightly interpreted illustrates in a striking manner the production of electrical from mechanical energy. *If the relative position of two conductors, A and B, be changed, of which A is traversed by a current, a current is induced in B in such a direction that by its electro-dynamic action on the current in A, it would have imparted to the conductors a motion*

OF THE CONTRARY KIND *to that by which the inducing action was produced.* If A approaches B, B is *repelled*; a current in the opposite direction is induced, and currents in opposite directions repel one another. If A is removed from B, it is *attracted*; that is, a current in the same direction is induced, and such currents attract one another. To speak more plainly, the tendency of the induced current is to move the bobbins in the opposite direction from what you try to move it. The experimenter in separating or bringing the bobbins together must exert force, do work, and this mechanical energy appears as the energy of the induced current. If, when approached, a current which attracted was induced, the phenomenon would be wholly inexplicable. In such a case, we would have a certain definite initial force producing another force without diminution of its own intensity. It might be compared to a boy sliding down hill upon his sled and accumulating sufficient momentum to carry himself and a fellow coaster to the top of an equal hill on the other side of the valley. Of course, in returning, each could carry a companion back to the summit of the first hill, and thus an indefinite amount of force might be accumulated.

Electricity is convertible into all the other forms of force, either directly or indirectly.

a. Mass motion is produced when two conductors containing parallel currents are brought near together; for, the wires are attracted.

b. Heat is produced whenever electricity traverses a poor conductor; as, a fine platinum wire which may be made red hot, thus at the same time giving forth *light* as well as heat.

c. Magnetic effects are produced when a current is passed through a helix containing a bar of soft iron or steel; in this case the soft iron becomes a temporary, and the steel a permanent magnet.

d. Chemical separation occurs when the terminal poles of a battery are placed in acidulated water; the water is decomposed into its constituents, oxygen and hydrogen, oxygen always appearing at the positive and hydrogen at the negative pole. In

this case electrical energy performs work which appears as the potential energy of chemical affinity.

e. Chemical combination takes place when the electric spark passes through a mixture of oxygen and hydrogen; the gases combine and form water. We would have, at the same time, heat, light and sound.

f. Gravitation. When an electric engine raises a weight to a given height, electrical energy appears as the potential energy due to gravity.

Latent Heat.—To melt a pound of ice at 0° requires 80 units of heat, and to change one pound of water at 100° C. to steam at the same temperature involves the consumption of 540 thermal units. The energy required to melt the ice would raise a one pound weight 111,200 feet high, and that which converts a pound of water into steam, would raise the same weight 750,600 feet high. Now, what becomes of this heat said to become *latent*. Surely it is not lost. The change from water to ice is a re-arrangement of the molecules which may be considered as acting on each other by certain polar forces. Each molecule of water seems to act like a minute magnet having a positive and a negative pole. At temperatures above zero the molecular vibration is so rapid that these opposite poles are unable to satisfy their tendencies to unite, and the water keeps the liquid form. As the water approaches zero, the vibrations decrease in intensity until at a certain point the polar forces act more powerfully than the repulsive forces due to heat, and opposite poles seize upon each other, forming ice crystals. In springing into these new positions the molecules must strike together with great force, and this is made known to us by the sensible heat invariably produced when a liquid solidifies. Once locked together, an immense force is required to separate these molecules. If the opposite poles of a great number of magnets come in contact, considerable work must be done to separate them. The energy represented by eighty units of heat is required to separate the miniature magnets found in a pound of water; and after separation the temperature is the same as before. Again, the molecules of water cling

to each other tenaciously. At 100° Centigrade, however, they vibrate with such velocity that their molecular attraction is overcome; but the force used up as work in separating them is enormous, being for water 540 units of heat for each pound changed to steam. This number of units would be sufficient to raise 5.4 lbs of water from zero to the boiling point of water. We may, therefore, regard the *latent* heat of steam, as it is called, as heat transformed into work used up in overcoming molecular attractions. But when this steam condenses, we know that it gives back all this so-called latent heat. The work done in changing the water at 100° to steam at 100° placed the molecules in a state of potential energy. So long as in the state of steam, the attractive forces cannot act across the inter-atomic spaces. Allow it to cool and the velocities of the molecules become less; they suddenly dart across these spaces and the shock of meeting shivers the ether so powerfully that all our latent heat becomes sensible again.

It thus appears that whether we consider a body falling to the earth on account of gravity, a planet revolving about the sun, or the particles of steam thrown from the liquid surface by the action of heat, in every case the energy which seems to have concealed itself, which seems to have been lost, can be accounted for with little less than mathematical precision. In what has preceded I have endeavored to impress upon the mind two principles:

First, The Correlation of Physical Forces. You who have followed with some care have seen that the forces of nature, Light, Heat, Electricity, Magnetism and Chemical Affinity, seem to be linked in a common brotherhood. Given any one, and, under suitable conditions, either one or all the others may be produced. Force may, in this respect, be compared to an individual having many suits of clothes. It can change its outward apparel at will, but in all forms and disguises we are sure of the presence of the same identical thing, MOTION.

Second, The Conservation of Energy. The total amount of energy in the universe is a constant quantity. We cannot subtract the smallest fraction. Neither can we add to the sum

total. We can change its form, but amid all possible transformations, transmutations and appearances it continues the same unvarying, undiminished quantity.

LECTURE VI.

GRAVITATION.

To the thoughtful minded it is a source of unceasing delight to search for the intimate causes of things. The universe in its minor details no less than its grander exhibitions seems to have been built through the action of fixed and immutable laws. To discover these laws and apply them to the explanation of known facts is the province of the scientific mind. To explain a phenomenon is to refer it to a known law. It was the habit of the ancients, and is still among savages and semi-civilized men, to refer all unusual events to the immediate intervention of a Supreme Being. The enlightened man demands an explanation based upon natural causes which are invariable in their mode of action. He is willing, if you please, to admit that a Supreme Being is the cause of the law, but not that he controls *directly* the particular phenomenon in question. The scientific man regards the Universe as an immense clock. The clock has been wound up and is running down. We are in the clock among the cogs and pinions. We can see the mighty revolving wheels, hear the roar of the machinery; and can even feel the heat from the ponderous boiler. A savage would expect to find an imp or a

demon in the clock to turn the hands.* The enlightened mind studies the mechanism and seeks to find the main-spring.

* The peculiar nature of the force of gravitation, as it is called, has perplexed physicists ever since Newton. We say two bodies attract one another, but what do we mean? Attraction may be defined as the mutual pull which two bodies exert on one another tending to draw them together. We accept attraction as a fact, but how can two bodies act on each other at a distance? How can a particle of matter act where it is not? It is inconceivable. And yet it is an established fact that particles do act on other particles millions of miles away, and what is the strangest part of it, they act, as I shall show you further on, *instantaneously*. The fact proves that our conceptions are not the measure of possibility. See this large magnet. I present it to a suspended magnetic needle and the latter is powerfully attracted. I place a jar of thick glass over the needle. When I

* Forces are causes and are known by their effects. If a given cause a has a given effect b , then $a = b$. In turn, if b becomes a cause and produces an effect c , and c in its turn is the cause of d , then, we may say, $a = b = c = d$. In this case, a is called the *primary*, and b , c and d *secondary causes*. The causes with which we deal in nature are all secondary. Cause a will probably never be reached. It follows from the nature of an equation that no term or part of a term can be lost or become nothing. Causes are therefore said to be indestructible. Notice that a in producing b must cease to exist. If b is not quite equal to a , then some of a must appear as another effect e . And then, $a = b$ plus e . As, from the nature of causes, $a = b = c = d$, in which a becomes successively b , c , d , we must regard them all as forms of the same thing. Causes, then, are convertible. There are two kinds of causes which are inconvertible. *Matter* is the invariable cause of the effects weight and impenetrability. *Forces* want these properties and are hence called imponderables.

It is noteworthy that matter and force are always found associated. In fact, we are ignorant of force except as it affects matter. This suggests the query whether there be such a thing as pure force. Since matter and force are never separated, may they not, after all, be identical? Not a few philosophers have seriously urged this doctrine. By simply assuming each molecule of matter to be a center of force we can account for all its properties. Regarded in this light, matter and force are one and the same. If I touch an object it repels my hand. A solid body is simply an accumulation of repellant forces. Impenetrability is due to the vigor with which these force-centers resist every attempt of exterior forces to displace them. There is abundant experimental

present the magnet it acts as before. Placing a sheet of copper, in addition, between the magnet and needle it acts with undiminished intensity. I add a sheet of zinc; it makes no difference. I now place the copper, zinc, and a piece of sheet iron together, leaving the needle under the jar; on presenting the magnet it acts, apparently, with its whole force through all these substances. I now place the needle stand on the air-pump plate, cover with the bell-jar and exhaust the air. Through zinc, copper, iron, glass and a vacuum of three inches this wonderful magnetic force penetrates without seeming loss of intensity. I place myself between the magnet and needle. It acts all the same. A thick book and a block of wood are penetrated with equal ease. Surely this is a marvelous force with which we are dealing. And yet it is almost an exact representative, on a small scale, of the force of gravitation.

Although we cannot conceive of matter acting on other matter at a distance, we are familiar with phenomena of electricity supposed to take place through the so-called *polarization of intervening particles*. Many of Faraday's researches point to polarization as a probable mode of action of electrical forces at a distance. Thus, we know that, although the electric spark will pass readily through a partial vacuum, it refuses to do so in a

evidence attesting the fact that the so-called molecules of matter are never in mathematical contact. We see then, that whether a so-called molecule is matter, *stuff*, or a repellant *force-center* we are driven to the conclusion that action occurs because of repulsion and not on account of contact. On the matter-force hypothesis, matter would be infinitely compressible; the amount of condensation simply depending on the ratio of the exterior to the interior force. From the above it will be seen that we are ultimately forced to admit that matter only acts on other matter at a distance. The readiness with which light penetrates glass indicates that the molecular interspaces are large; and hence the molecules are separated by great distances compared with their diameters. Does an elastic atmosphere bathe the molecules and serve as the medium by which they act on one another? This last hypothesis seems now the most acceptable one. But if so, how does it act and what is it? These speculations however, are leading us beyond the bounds of legitimate inquiry on account of a lack of knowledge, and they are only presented as queries to show how meagre is our information respecting the real nature of matter and force.

perfect one, even if urged by a powerful Ruhmkorff coil. By *polarization*, it is meant that the force acts first on the layer of adjacent particles, these on the next layer and so on through successive layers until the last layer acts upon the second body. Of course the number of particles acted upon would be enormous and the intervals between the actions on successive particles inconceivably small. Sir Isaac Newton once wrote in a letter to a friend that, in his opinion, that man was incapable of sound philosophical reasoning who would seriously argue that force could be transmitted from body to body in the absence of a medium of propagation. The hypothetical luminiferous ether has been suggested as also the medium of propagation for the gravitating force. The most fertile minds, however, have failed to frame a hypothesis by which the ether could act and account for the known effects.

Gravitation acts alike whether bodies are cold or hot; in separate molecules or large masses; whether other similar particles intervene or not. The only theory that has ever been deemed at all worthy of consideration is that of Le Sage, of Geneva. It is known as the theory of impact, and consists in the assumption of the existence of an infinite number of ultra-mundane corpuscles—infinitely small, but darting about continually with high velocities. A lone planet in space would be pelted equally on all sides by these miniature hail stones. Two planets in proximity would mutually screen one another; but only on the sides which faced. It will be seen that this impact of particles or corpuscles would tend to drive the bodies together. For small bodies, it can be shown that this force of impact would vary inversely as the square of the distance; but for large masses, like the earth, we must also assume that the corpuscles act on each separate molecule of matter as though it stood alone. In other words, this miniature rain-storm is as effective upon the particles of the earth's interior as on its surface. But, we may ask, whence come these innumerable corpuscles? Have they been beating upon the earth through all past time? And, if so, is their number infinite, so that their

action will never cease? As we proceed to examine this hypothesis, we shall find so many objections to it that it becomes, in its present state, entirely untenable.

With these preliminary considerations, I shall now pass to the action and consequences of the law. It is usually expressed as follows:

The attraction between two material particles is directly proportional to the product of their masses and inversely as the square of their distance asunder. It is expressed by the formula,

$$a \propto \frac{mm'}{d^2},$$

where a is the attraction, d the distance, and m and m' their masses. This law is universal. It controls the motions of the planets, satellites and comets of space, no less than of a meteor or falling stone at the earth's surface. There seems to be no doubt that it penetrates still further into space and rules the entire sidereal systems which the most powerful telescopes bring into view. Astronomers have discovered that certain stars once thought to be single are in fact double. Powerful telescopes have further demonstrated that one of these stars revolved about the other, thus presenting a central sun and its planet ruled by the same force that holds a stone to the earth. As an example to illustrate the application of the law of inverse squares, let us calculate the weight of one pound on the earth's surface if it were removed to the distance of the moon. We must regard the mass of the earth as though it were concentrated at its center of gravity or geometrical center. Then, since the moon's distance is 60 times the earth's radius and a body at the surface once that number, we have the proportion:

Attraction at earth : attraction at moon

$$\therefore \frac{1}{(1)^2} : \frac{1}{(60)^2} \text{ or, } 1 : \frac{1}{3600}.$$

From this we see that the mass of a pound would weigh only about two grains if removed to the moon. The moon revolves about the earth once a month, being retained in its path by

the combined action of centrifugal force and gravity. Knowing the diameter of the moon's orbit, its circumference can be obtained by multiplying by the number 3.14159. If this quantity be divided by the number of seconds it requires for the moon to traverse its orbit, we shall have the arc passed over in one second. Draw now a tangent to the arc at one extremity. The distance from the other extremity to the tangent represents the space through which the moon *actually falls in every second of time*. Representing this space by d , the diameter of the moon's orbit by D , and the arc by A , and we have, by a principle of geometry, approximately:

$$D : A :: A : d.$$

$$d = \frac{A^2}{D}.$$

The diameter of the moon's orbit is 480,000 miles. This distance is traversed in 27 days, 7 hours, 43 minutes, and 11 seconds. By substituting these numbers in the equation, we find $d = .0534$ of an inch. The moon then falls toward the earth .0534 of an inch in every second of time. But since the tangential force just equals this number, its mean distance from the earth remains constant. I advise all to work this problem, as there are many interesting things connected with it. You will find, for example, that in each second the moon moves about 33,000 feet, or nearly three times the velocity of a bullet. The deflection of 1-20th of an inch in a second hardly deviates it from a straight line. In fact, its course is more direct than that of any projectile on the earth.

Now, on the supposition that gravity varies inversely as the square of the distance, let us compare the theoretical fall with that just computed. The following proportion gives it:

$$(60)^2 : (1)^2 :: 16.1 \text{ feet} : (x)$$

$$x = \frac{193}{3600} = .0536 \text{ of an inch.}$$

This result agrees nearly with the other, and I have introduced it because it is the identical problem which Newton first solved when the great law under consideration first dawned upon him.

I think you will conclude by the time you have solved it completely that it is not to be deduced from the fall of an apple. The fact is, that Newton first undertook this calculation by using a wrong value of the earth's radius. He found that the computed and theoretical values disagreed by one-sixth of the whole. This made him lay aside the work for several years until accidentally hearing of a new determination of an arc of the earth he computed the true radius. From this he found the two values about identical. But Newton did not stop here. He applied the law to the planets and comets and showed in his immortal work, the *Principia*, by the most abstruse mathematical deductions, that Gravitation is universal.

In the light of the conservation of energy, how must this force be regarded? As all terrestrial objects removed from the surface of the earth may be considered as in a state of potential energy, depending upon their weight and height, so all separated masses of matter in the universe, whether they belong to the earth, moon, sun or ultra-mundane planets, must be considered as possessing an energy of position. So long as separated, the attraction between their particles is unsatisfied. They are in the condition of a weight raised up. Should the moon cease to move in its orbit, it would fall to the earth and its present potential energy would be changed to heat. Should the earth stop in its orbit, it would fall into the sun and sufficient heat would be produced to cover the present solar emission for nearly a century. While the planet Jupiter, falling from its position of 500,000,000 miles away into the solar center, would furnish heat sufficient to supply the sun for more than thirty-two thousand years!

According to Richard H. Proctor, the action of the gravitating force is instantaneous:

"Light, which travels with such velocity, which travels 185,000 miles in a single second, takes eight minutes to reach us from the sun, so that when we look at the sun we see him not in the place he actually occupies in the ecliptic, but the place he occupied eight minutes before. And this leads to the strange consideration that if gravity, the force by which the sun

rules the earth were to occupy the same time in passing over the interval which separates the sun and the earth that light does, the years would grow continually longer. Let us suppose the earth traveling from my left to my right around the sun, which is directly opposite. When a body is traveling forward against a material shower such as rainfall, the shower will seem to come somewhat from the direction in which the body is moving. Thus the light from the sun comes somewhat obliquely to meet the earth. Suppose the force of attraction occupied the same time; that force would occupy a line, not from the sun, but from a point on the right of the sun; it would draw the earth, not towards the sun, but somewhat in the direction toward which the earth is moving, and there would be a continued increase in the earth's velocity and an increase in the length of the year; and this would be manifested in a few years, and still more in the hundreds of years during which astronomy has been a science; and because there has been no appreciable increase in the length of the year, it is shown that the force of gravity acts instantaneously; that it acts very much more quickly than light."

If asked to give the probable mode of action of the gravitating force, we must answer, *wave motion*. As yet, however, the most powerful scientific minds have failed to frame an hypothesis, founded upon the action of waves, which can account for the phenomena. Any hypothesis based upon an actual translation of matter, is, to say the least, contrary to all analogy. In proportion as we become intimate with the action of forces, we get more and more confident that the only way by which force can be transmitted from place to place is through the intervention of matter. And while in the *act* of being transmitted it exists, in every case, so far as we know, as *wave motion*. Of course, we except from the above statement the transference of kinetic energy by the movement of masses of matter, and refer to the modes of occurrence and propagation of the natural forces. Vibrations from 32 to 73,000 per second are known to produce the sensation and effects of sound. *Vibrations somewhere between

100,000 and 200,000,000,000 per second are thought to produce electrical effects. If the oscillations are so rapid that from 200,000,000,000 to 400,000,000,000 are produced in a second, we know the effects to be those of heat. From 400,000,000,000 to 800,000,000,000 oscillations per second are manifested by optical, thermal and chemical effects. While all above eight hundred billion per second produce only chemical action. If we except the cause of electrical effects, all the above statements are founded on sound theoretical and experimental bases. Will it ever be possible to place magnetism and the gravitating force in the above series? Such a culmination of our knowledge does not seem to be very near, but it is not reserved for any one to set the bounds of scientific discovery and generalization.

LECTURE VII.

THE PERPETUAL MOTION—IT IS A PHYSICAL IMPOSSIBILITY.

In a certain sense, all motion is perpetual. In some form or other it will exist forever. Now, if this principle of the conservation of energy be true; if no force can actually be annihilated; if the energy which drives a scheme of wheels still exists in some of the protean forms common to motion, the question arises, cannot this same force be re-collected and made to drive another machine, or, perchance, to keep this first machine in motion without end?

The force used to propel machinery disappears, first, as *work*; second, *heat*; third, *sound*; fourth, *electricity*. We say that it disappears, meaning that it exhibits itself in these forms. These quantities added together equal the original motive power. If collected, would they do the same work? Can they be collected? These are the questions to be solved in deciding the possibility of a perpetual motion. The universally received notion of *the perpetual motion* is that of a system complete in itself, which shall generate the force necessary to keep its parts in motion, and at the same time, do useful work. The steam engine consumes coal, and coal is money. Animals cannot work without food, and this means money. But work is gold. A machine capable of doing work, and at the same time running itself, would not only be a marvel; it would be a fortune. Hence we find that the philosopher's stone and the perpetual motion have been sought by both fools and philosophers since time immemorial.

In order to get the idealist's perpetual motion, force must act in a complete cycle. Starting with a given initial force as a motor, it must drive its scheme of wheels,—and there must be wheels to turn if the machine is of any practical value—and then, returning to its first condition, after various transmutations, it must again become a motor. This cycle must be capable of infinite repetition. But, if the system is to be of any use, it must do more than this. Work must be done, and this means that resistance must be overcome. The initial force, which acts as motor, must revolve its scheme of wheels, do a certain amount of work, complete its first cycle, and commence the second with the same force as in the beginning. If we admit the possibility of such a cycle, then we must assume that work can be done without the expenditure of force.

Take a very simple machine as an illustration. Attach a weight to a rope hung over a pulley. In falling a given distance, this weight will, theoretically, raise an equal weight to the same height on the other side. Weight (2) can draw (1) back again to its former position, provided some one gives it a start to overcome the inertia. Even supposing this to occur, it is evident that it would be of no practical value, since all the force is required to keep up the see-saw motion. No machinery could be attached in order to get work from the system. But, as every one knows, it would not work at all, on account of the friction on the axle and the resistance of the air. In order to act continually, each weight must raise another *a little heavier than itself*—a physical impossibility, as any one could tell you.

Let us try another plan. By means of some motor, two metallic discs are made to rotate in close contact, so that on account of the friction they become red hot. May not the radiant heat from the discs be used to produce steam, which in turn shall run the discs? Practically, such a system would not run a moment, on account of the friction of the machinery, if for no other cause, and the force represented by the friction and sound is of such a nature that *it cannot be collected* and utilized again. Again, even if we ignore the difficulties already pointed out in such an

arrangement, we could do no work with the system, because it must not be forgotten that *in the performance of work a given amount of heat ceases to exist as heat*. It is found, for example, that less heat passes into the condenser of an engine when it is doing work than when it is running and not working.

The discovery of magneto-electricity was thought by some to furnish a key to the long-sought perpetual motion.

"A speculative American set some time ago the industrial world of Europe in excitement. The magneto-electric machines often made use of in the case of rheumatic disorders are well known to the public. By imparting a swift motion to the magnet of such a machine we obtain powerful currents of electricity. If these be conducted through water, the latter will be reduced to its components, oxygen and hydrogen. By the combustion of hydrogen, water is again generated. If this combustion takes place, not in the atmospheric air, of which oxygen only constitutes a fifth part, but in pure oxygen, and if a bit of chalk be placed in the flame, the chalk will be raised to a white heat and give us the sun-like Drummond light. At the same time the flame develops a considerable quantity of heat. Our American proposed to utilize in this way the gases obtained from electrolytic decomposition, and asserted that by the combustion a sufficient amount of heat was generated to keep a small steam engine in action, which again drove his magneto-electric machine, decomposed the water and thus continually prepared its own fuel. This would certainly have been the most splendid of all discoveries; a perpetual motion, which, besides the force which kept it going, generated light like the sun and warmed all around it. The matter was by no means badly cogitated. Each practical step in the affair was known to be possible; but those who at that time were acquainted with the physical investigations which bear upon this subject, could have affirmed on the first hearing the report that the matter was to be numbered among the numerous stories of the fable-rich America; and indeed a fable it remained."*

* Helmholtz, "Interaction of Natural forces."

If we except living animals the steam engine or *heat engine* is the source of almost all our power. Long since it was pointed out by the Frenchman Carnot, that in all cases, when work is done by an engine, heat must pass from a reservoir of higher to one of lower temperature. And, further, that in no case could heat be made available for work unless there were two adjacent regions in different thermal conditions. On this account he compared a steam boiler to a reservoir of water. As the water is valueless unless it occupies a higher level than the surrounding surface, so in the first case you can get no work unless the boiler is at a higher temperature than the air. Given an ocean of water on the same level, and it would be useless for turning mill stones. Given a mammoth steam boiler at a certain temperature; it is useless, unless the atmosphere surrounding it has a different thermal state. After performing its work, the heat from the steam boiler falls to that of a lower temperature, gradually, but surely, attaining that of the enveloping medium. The heat still exists, but it is in such a condition that it can do no work. It is also the case that, if the work to be done is considerable, the temperature of the boiler must be very high. Reasoning on this principle, Professor J. Thomson suggested that the application of pressure would lower the freezing point of water, and it was afterwards proved experimentally by Sir W. Thomson. The former reasoned as follows.*

“Suppose we have a chamber kept constantly at the temperature 0° C., and that we have a cylinder, of which the area is one square meter, filled one meter high with water. Suppose, next, that a well fitting piston is placed above the water in this cylinder, and that a considerable weight is placed on the piston. Let us now take the cylinder, water and all, and carry it into another room, of which the temperature is just a trifle lower. In course of time, the water will freeze, and, as it expands in freezing, it will push up the piston and weight about 9-100ths of a meter; and we may suppose the piston is kept fastened in this position

* Stewart's “*Conservation of Energy*” (110).

by means of a peg. Now carry back the machine into the first room, and, in the course of time, the ice will be melted, and we shall have water once more in the cylinder, but there will now be a void space of 9-100ths of a meter between the piston and the surface. We have thus acquired a certain amount of energy of position, and we have only to pull out the peg and allow the piston with its peg to fall down through the vacant space, in order to utilize this energy, after which the arrangement is ready to start afresh. Again, if the weight be very great, the energy thus gained is very great; in fact, the energy thus gained will vary with the weight. In fine, the arrangement now described is a veritable steam engine, of which the chamber at 0° C. corresponds to the boiler and the one a trifle lower to the condenser, while the amount of work we get out of the engine—or, in other words, its efficiency—will depend upon the weight which is raised through the space of 8-100ths of a meter, so that, by increasing this weight without limit, we increase the efficiency of our engine without limit. It would thus, at first sight, appear that by this device of having two chambers, one at 0° and the other a trifle lower, we may get any amount of work out of our water engine; and that, consequently, we have managed to overcome Nature. But here Thomson's law comes into operation, showing that we cannot overcome Nature by any such device, but that, if we have a large weight upon our piston, we must have a proportionately large difference of temperature between our two chambers." In other words, the water refuses to freeze under this high pressure. Lower the temperature still more and it becomes a high pressure engine and can raise a heavier weight, *i. e.* do more work. The foregoing illustrates the state of things with every heat engine. Heat is changed from that of a high to that of a low temperature. Practically, it cannot be collected, and, if it could, it has suffered a species of degradation such that it would be unavailable as energy. The complete discussion of this subject will be reserved for the lecture on the sun, under the topic, *Dissipation of Energy*, where it will be seen that inferences from these facts lead us to startling conclusions respecting the

future of the Universe. All power must be drawn from some existing reservoir of force, and every time it is used, it falls to a lower and lower level, from which no device of man can ever elevate it.

The problem of a perpetual motion has perplexed men of all ages. Although it has long been regarded by physicists as an impossible contrivance, the unlearned are still in search for it, and we frequently hear of "Keeley motors" and "non-gas-burning" engines which, in the language of the inventors, "are to revolutionize the motive power of the world." For good reasons, however, these wonderful devices never survive more than one or two puffs of the newspapers. A fire with an infinite supply of fuel; a clock weight, which is ever falling, but which never strikes the earth; a living animal without food; a light which needs no replenishing; a galvanic cell which consumes no zinc; a moving engine without a motor; in fact, a phenomenon without a cause; an active productive energy from that which does not exist; *something from nothing*,—all these are implied in the chimera of the perpetual motion as it is usually understood.

LECTURE VIII.

CORRELATION OF VITAL AND PHYSICAL FORCES.

All physical and chemical forces have been shown to be correlated. Now may not a relation exist between these and vital force? Admit we must that the relation, if it exists, is a profound one. It does not appear upon a superficial view. But the same may be affirmed of the other forces of nature. Compare the flash of an electric discharge with the attractive force of a magnet. Their effects are wholly unlike. And yet we know that magnetic force may produce electrical effects, and electric force will develop magnetism. If it can be shown that whenever vital force appears, some form of physical or chemical force disappears, and that the quantity which appears is, in all cases, proportional to that which disappears, we shall have taken a long stride toward establishing a relation between these three forms of force. And here let me say that by *Vital Force* is meant all manifestations of activity in animals or plants aside from those connected with the mind. Such, for example, as muscular energy, the action of the heart and digestive apparatus and more especially the energies which perform the work of tissue building, of waste and repair, come under the head of those to be considered. Organic beings are distinguished from inorganic, by development from an embryo; gradual growth to the adult state, in which they resemble the parent; a constant process of growth and decay of tissue; reproduction and finally decay.

There are several processes which consume force in the organic body. First, there is the work of tissue building, in which

material is transported from place to place and raised from lower to higher planes of existence, from simple to complex compounds. Then there are mechanical and muscular energies which enable the plant or animal to do work. Finally, there is the heat which is so essential to life and growth. All these demand force. Where does it come from? Is it created in the animal body or must we seek it elsewhere? Nothing can be clearer than the fact that an animal derives its force from the food which it eats. Carnivorous animals eat those which are herbivorous, and these last subsist upon plants. Plants, again, feed upon compounds, and these compounds are built up from the chemical elements.

Before going farther, it will be necessary to compare organic and inorganic bodies with reference to the nature of the molecules which compose them. The most marked characteristic of inorganic structures is their stability. All organic bodies are highly unstable. The rocks which constitute the earth's crust are almost indestructible, while animal organisms are constantly changing. When life quits the animal body, decomposition immediately sets in, and, in less than a year, if exposed to the air, all but its solid constituents, the bones, are gone. Now, this difference between these organic and inorganic molecules is of great importance. Carbonic acid, water and ammonia may be taken as the typical inorganic compounds; and starch, sugar, cellulose or woody fibre, and albumen, as types of the organic molecules. Now, all of us know that the first three are very stable, are shaken to pieces with extreme difficulty. In truth, water and carbonic acid are products of combustion—ashes, in fact. They have fallen from the highest to the lowest plane of existence, if we except the elementary form. Starch, sugar and albumen are raised high above the plane of elementary existence. Their chemical formulas are complex; they contain, in each molecule, an immense number of atoms. And these atoms are held together by forces so weak that they fall asunder upon the slightest provocation. How readily an egg becomes addle; it is due to the large quantity of albumen which it con-

tains. Muscular tissue, such as lean meat, is with difficulty preserved from decomposition. It consists largely of albuminoids, which contain nitrogen, besides carbon, hydrogen and oxygen, of which sugar, starch and the fats are composed. It may be stated, as a general principle, that compounds containing nitrogen are usually highly unstable. Nitro-glycerine, gun-cotton, gunpowder, and chloride of nitrogen, are well known examples of the above law.

Sugar, starch, cellulose and the fats, it should be remembered, are comparatively stable when pure. But it requires the presence of only a small quantity of albuminous material to cause them to decompose. Notice how readily butter becomes rancid if the nitrogenous caseine of the milk be not all removed, or how sugar can be made to ferment by the addition of yeast. According to Professor Joseph Le Conte there are four planes of existence whose relations may be well expressed by writing them one above the other, as follows:

4. ANIMAL KINGDOM.
3. VEGETABLE KINGDOM.
2. MINERAL KINGDOM.
1. ELEMENTS.

And further, there is a particular force whose special function it is to move matter from any plane to the one above, and also to execute all movements on that plane. It is the province of chemical force to raise matter from plane (1) to plane (2), as well as to preside over all movements on plane (2). Vegetable life force lifts matter from (2) to (3), and executes all changes which take place on plane (3). While it is the sole province of Animal life force to elevate matter from (3) to (4), and also to perform all evolutions upon that plane. In rising from the second to the highest plane a process of building up is going on and force is consumed in performing this work of tissue building. In falling back from (4) to (3), and then from (3) to (2), this force previously consumed is set free. Notice that matter cannot, at one bound, rise from plane (1) to (3), nor from plane (2) to (4). There is no single force capable of lifting matter at once through these sta-

ges. Plants cannot feed upon elements; neither can animals subsist upon minerals.

As the food of plants then, we have carbonic acid, water and ammonia, with a little sulphur, phosphorus, iron and other elements in traces which we may neglect in this argument as unimportant. Our first work of tissue building takes place in the green leaf under the influence of sun light. The presence of chlorophyl and living protoplasm in the leaf seems to be absolutely necessary. Sunlight, in the presence of this protoplasm seems to possess the power of shaking asunder the extremely stable compounds of water and carbonic acid; the excess of oxygen or hydrogen is thrown off and the remainder goes to make up plant-tissue. The force needed to build the tissue would be present because all the elements in a nascent state have a powerful tendency to combine, probably because the forces which previously linked them are then free. Here, then, we have light, physical force, disappearing as light and reappearing as the potential energy of organic tissue or vegetable life force. The light is used up in performing the work of decomposition; it appears as nascent chemical energy, and this again is applied to the work of forming organic matter, again to reappear as vital force in the tissue formed. "As sun-heat falling upon water disappears as heat, to reappear as mechanical power, raising the water into the clouds, so sunlight falling upon green leaves disappears as light, to reappear as vital force lifting matter from the mineral to the organic kingdom."

But, with the majority of plants, growth takes place at night and in the absence of light. There are two ways of accounting for this. In the first place it may be that more material is decomposed during the day than the plant can work up into organic matter. During the night or in cloudy weather a portion of this unorganized material would fall back to its old state as carbonic acid, water or ammonia. In falling back, heat would be produced and the force might be used to raise other portions of matter higher up. That is to say, matter, in falling from a place between planes (3) and (2) to (2), generates force to push other

matter up to plane (3), or, perhaps, moves it about on that plane. Again, all rich soils contain considerable quantities of soluble humus, or decomposing vegetable matter. This may be taken up in the sap of plants and elaborated into tissue. For, a portion of this humus in falling from between planes (3) and (2) would generate sufficient force to raise other portions up to plane (3) and perhaps to perform evolutions on the third plane.

But it is a well known fact that seeds commence to grow in the dark, where light from the sun cannot possibly reach them. In this connection it should be borne in mind that all seeds possess a store of nutriment which is used up in the process of germination. In some seeds we find starch, oil and perhaps sometimes sugar. Warmth, which is needed before germination can set in, seems to start the decomposition. A portion of the starch or oil falls down to a lower level and thus generates force to raise another portion higher up, or to move it about on its own plane. In this way a seed furnishes within itself, the germ, the force, and the material for its first growth. On peeping above the surface it first commences to get its force from the sun and to draw upon the mineral kingdom for new supplies of material. In a similar manner we can explain the starting of buds and of sprouts in the dark.

In the development of an embryo in the egg, we have a somewhat similar process. An egg consists of a mass of organic matter in an unorganized condition, so to speak. It is matter on plane (4), but on the lowest part of plane (4). In order to become a chick, it must be elaborated into delicate tissues, brains, feathers, etc., and this implies the consumption of force or work. Now, this force is supplied by the egg itself. For, an egg, in the process of incubation, is found to absorb oxygen and give off carbonic acid and water, and loses weight. Thus combustion proceeds within the shell. Force is set free and applied to producing the highly organized tissues of the animal. In this way, a small quantity of material, in falling from (4) to (2), furnishes force to move the remainder about on plane (4), and finally appears as *animal life force*—*Vital force*. It seems, then, that the

force of decomposition—*chemical force*—set free in the egg, finally manifests itself as *vital force* in the chick.

Herbivorous animals subsist upon plants, carnivorous animals upon those which are herbivorous. Plants have been raised to a highly organized state by the action of sunlight. They are, so to speak, delicately poised upon a pinnacle, ready to fall at any moment and have their potential energy become kinetic. In the bodies of animals, these materials on plane (3) are a portion of them decomposed for the production of heat and mechanical energy; another portion produces force to raise matter from (3) up to (4). We must not forget, however, that in the healthy animal body, waste and repair are both going on continually. Now this waste is of itself the source of a vast amount of energy. Highly organized animal matter, in falling down to carbonic acid, water and urea sets free an immense quantity of force. A portion of this goes to produce animal heat, still more, muscular force, and perhaps some of it is utilized in the work of building tissues. Carnivorous animals eat food already highly organized, either as fatty material or albuminoids, which last are absolutely essential to life. Fat, in consuming, furnishes heat and force; hence, fatty foods are especially desirable in cold climates. The albuminoids may enter into the composition of tissues, or, by their decomposition, they may produce heat and force, both of which are essential to life. A starving animal lives upon the force generated from the decay of his own tissues, and, in all cases, Vital Force, as exhibited in the animal body, seems to arise from *chemical decomposition*. It is, therefore, intimately connected with, and is correlated with, the force of chemical affinity. Such is an outline of the nature of vital force, as given by Professor Le Conte.

This question has, within the past twenty years, engaged the attention of such scientists as Helmholtz, Mayer, Liebig and Carpenter, and all unite in the belief that the forces of organized beings emanate from the same great force-center as do the other energies of nature. All food is matter in a state of unstable equilibrium. It may be likened unto a loaded rifle, cocked, with

a hair trigger, or to a weight delicately suspended upon a lofty pinnacle. Touch the trigger, or cut the thread which holds the weight, and instantly an immense amount of energy is set free. Introduced into the stomachs of animals, the food rapidly falls back into the mineral kingdom, bequeathing to the higher organism its late potential forces. Coal is also matter in a state of potential energy, and were our stomachs, like the steam engine, capable of digesting it, we would be able to evolve from it all the effects produced by the engine. In fact, every animal is a veritable steam engine. We can work an engine by direct combustion of the food used by animals. The effects of combustion in our bodies are precisely those going on in a furnace. The only difference is in the intensity, carbonic acid and water being the products in both cases.

The amount of food needed to enable a man to perform a given amount of work can be calculated with as much ease as we can determine the coal necessary for an engine. For, nothing is created in the animal body. The will is a guiding, a directive force, and not one which creates. If I walk up to the top of a mountain, 15,000 feet high, I can calculate the amount of carbon consumed in making the ascent. Suppose my weight to be 180 pounds, then it would require 2,700,000 units of work, or 1,935.2 units of heat. This is the equivalent of .24 of a pound of coal. Now, measured by a man's feelings, it would be an immense task to climb such a mountain, but you see that the actual work would be done by the burning of less than one-fourth of a pound of carbon. Plants are collectors of physical force, while animals are consumers. Solar radiation is locked up by the vegetable kingdom in the form of chemical tensions. Eaten by the animal, these tensions appear as mechanical energies. The steps in the transmutation are, therefore: solar radiation, physical force; chemical tension in the plant; mechanical energy or vital force in the animal body. Dr. Mayer, in his essay upon *Vital Dynamics*, has made some interesting calculations with reference to the force of animals:

"The mechanical work which corresponds to the combustion

of one unit of weight of coal corresponds to the raising of 9,670,000 units to the height of one foot. If we express by a weight of carbon the quantity of chemical force which a horse must expend to perform the above amount of work, we find that the animal in one day must apply 1.34 lbs; in an hour, 0.167 lb.; and in a minute, 0.0028 lb. of carbon, to the production of mechanical effect. According to current estimates, the work of a strong laborer is one-seventh of that of a horse. A man who in one day lifts 1,850,000 pounds to the height of one foot must consume in the work 0.19 lb. of carbon. This for an hour (the day reckoned at eight hours) amounts to 0.024 of a pound; for a minute, it amounts to 0.0004 of a pound, or 3.2 grains of carbon. A bowler who throws an 8-pound ball, with a velocity of 30 feet, consumes in this effort one-tenth of a grain of carbon. In climbing a mountain, 10,000 feet high, the consumption (not taking into account the heat generated by the inelastic shock of the feet against the earth) is equal to 2 ozs., 4 drs., 50 grs. of carbon."

"In order to enable them to convert chemical force into mechanical work, animals are provided with specific organs which are altogether wanting in plants. These are muscles. To the activity of a muscle two things are necessary: (1). The influence of the motor nerves as the determining condition; (2). The material changes as the cause of the mechanical effect. Like the whole organism, the organ itself, the muscle, has its psychical and its physical side. Under the former we include nervous influence, under the latter, chemical processes. The motions of a steamship are performed in obedience to the will of the steersman and engineer. The spiritual influence, however,—without which the ship could not be set in motion, or, wanting which, would go to pieces on the nearest reef,—guides but moves not. For the progress of the vessel we need physical force,—the force of coal; in its absence the ship, however strong the volition of its navigator, is dead."

The hydrostatic pressure of the blood in the arteries is known to be about 6.8 feet. From this fact Dr. Mayer calculates that the work done by the two ventricles of the heart in a day would

equal the mechanical energy competent to raise a weight of one pound 303,000 feet. This is about one-sixth the labor performed by a strong man in an ordinary day's work. Assuming the substance of the heart to be oxydized in order to supply the force for its own activity, the entire organ would be wasted in eight days. The muscular tissues of the ventricles themselves would last but three and a half days.

Mental Force.—Among eminent physiologists there is a growing belief that the energies of the mind are intimately related to the natural forces, and perhaps a brief notice of the facts leading to such conclusions will be of interest. The brain is universally admitted to be the organ of the mind. In that mass of nervous matter are stored all the ganglionic impressions which constitute memory, and by means of the nerves these impressions are conveyed outward. The active brain is known to consume more material than the inactive. Severe intellectual exertion causes a strong flow of blood to the brain. The increase in temperature thus caused has even been measured. A sensitive thermopile, (an instrument for measuring small changes of temperature), was applied to a man's head. Allowing the needle of the instrument to come to rest, it was found that a quiescent mental state could be attained such that no changes of temperature were noticeable. But a sharp knock upon the door, or simply a question asked would send the needle through many degrees; and this although not a word was spoken by the subject of the experiment. When the mind works hard certain waste products, whose constituents are peculiar to the brain tissue, are found to increase.

If a current of electricity be passed through a fine wire, heat is produced; and if heat be applied to certain metallic combinations a current of electricity is produced. Hence we say heat and electricity are correlated. Now if electricity be passed through certain nerves of the body nervous force is excited. Again, there are fishes whose nervous centers generate electricity. Why then may we not affirm that nerve force and electricity are correlated, and interchangeable? But the mind, through

the brain, acts on the nerves; and, conversely, the nerves act on the mind. Does this complete the chain of correlation between mind and electricity? "Every throb of pleasure," says Professor Bain, "costs something to the physical system. And two throbs cost twice as much as one." Perhaps the same might be affirmed of the other actions of mind. Every act of will, every thrill of pain, every retention of memory, every intellectual movement, may have its corresponding physical change; may have its exact equivalent in grains of carbon. In dealing with mind, however, we must admit that the majority of its phenomena will probably ever remain mysterious. Before we can investigate anything we must have tools more refined than that which we seek to examine. Since we study *Mind* with mind, how can we hope to penetrate to the root of its phenomena? How, for example, can we expect to explain memory, that wonderful faculty which treasures up the impressions of a life time. And yet Dr. Draper has suggested possible explanations, some of which are so beautiful that I beg leave to quote them:

"There are some simple experiments which illustrate the vestiges of ganglionic impressions. If on a cold, polished metal, as a new razor, any object, such as a wafer, be laid, and the metal be then breathed upon, and, when the moisture has had time to disappear, the wafer be thrown off—though now the most critical inspection of the polished surface can discover no trace of any form, if we breathe once more upon it, a spectral image of the wafer comes plainly into view; and this may be done again and again. Nay, more, if the polished metal be carefully put aside, where nothing can deteriorate its surface, and be so kept for many months, on breathing again upon it, the shadowy form emerges. Such an illustration shows how trivial an impression may be thus registered and preserved. But, if, on such an inorganic surface, an impression may be thus indelibly marked, how much more likely in the purposely constructed ganglion! A shadow never falls upon a wall without leaving thereupon a permanent trace, a trace which might be rendered visible by resorting to proper processes. * * Upon the walls of our most

private apartments, where we think the eye of intrusion is forever shut out, and our retirement can never be profaned, there exist the vestiges of all our acts—silhouettes of whatever we have done.”

“A duration of impressions upon the retina proves that the effect of external influences on nerve vessicles is not necessarily transitory. In this there is a correspondence to the duration, the emergence, the extinction, of impressions on photographic preparations. Thus, I have seen landscapes and architectural views taken in Mexico developed, as the artists say, months subsequently in New York—the images coming out, after a long voyage, in all their proper forms and in all their proper contrast of light and shade. The photograph had forgotten nothing. It had equally preserved the contour of the everlasting mountain and the passing smoke of a bandit-fire.”

“Are there, then, contained in the brain more permanently, as in the retina more transiently, the vestiges of impressions that have been gathered by the sensory organs? Is this the explanation of memory—the mind contemplating such pictures of past things and events as have been committed to her custody? In her silent galleries, are there hung micrographs of the living and the dead, of scenes that we have visited, of incidents in which we have borne a part? Are these abiding impressions mere signal marks, like the letters of a book, which impart ideas to the mind? Or are they actual picture-images, inconceivably smaller than those made for us by artists, in which, by the aid of a microscope, we can see, in a space not bigger than a pinhole, a whole family group at a glance?”

And yet, if Mr. Draper's beautiful image of memory could be fully established, it gives us no hint as to the nature of that occult force which contemplates these images of memory and shapes them to suit its liking. I can think of no more fitting words with which to close than some used by Professor Stokes in an address before the British Association: “When from the phenomena of life we pass on to those of mind, we enter a region still more profoundly mysterious. Science can be expected to do

but little to aid us here, since the instrument of research is itself the object of investigation. It can but enlighten us as to the depths of our ignorance, and lead us to look to a higher aid for that which most nearly concerns our well being."

LECTURE IX.

THE SUN AS A CENTER OF FORCE.

As the source of all terrestrial energy the sun deserves more than a passing mention in these lectures. It will be my main object in what follows to impress upon you the significance of the sun as a center of radiant energy, and, in order fully to do so, I must endeavor to give you a notion of his distance and enormous dimensions. In all the older works upon astronomy the mean distance of the sun from the earth is given as about 95,000,000 miles. This value was calculated by Encke from the observations made upon the transit of Venus, in 1769, and has since been shown to be too great by about 3,500,000 miles. Below is a table giving the elements of the sun as calculated by Chambers:

Mean distance from the earth, in miles.....	91,430,000
Diameter, in miles.....	852,584
Volume, (earth being 1),.....	1,245,130
Mass, " ".....	314,760
Density, " ".....	$\frac{1}{4}$
Specific gravity compared with water,.....	1.43
Angular diameter as seen from earth,.....	32' 3.4"
Horizontal parallax,.....	8.94"
Gravity, (earth being 1),.....	28
Rotates on its axis,.....	25 days, 10 hrs.

By *horizontal parallax* is meant the angle made by the earth's semi-diameter to an observer at the sun. It is by means of this

angle that the sun's distance is calculated, and the old value was $8.57''$. The new value of this angle is $8.94''$. Now, in order to show the extreme difficulty involved in taking astronomical measurements, I will say that this correction is equal to the breadth of a fine hair seen at a distance of 125 feet. One second of a degree subtends 450 miles at the distance of the sun. In round numbers we may regard the sun's distance as 91,500,000 miles. This statement, however, gives no conception of the distance. It is too great for the intellect to grasp. I might as well have said 91 trillions of miles. It is 400 times as far off as the moon. A cannon ball moving at its swiftest speed would require about 10 years to complete the journey. If air extended through celestial space the report of a solar explosion would reach us in 14 years. Light, moving 185,000 miles in a second, spans the enormous interval in 8 minutes and 18 seconds. It has been shown by several experimenters that sensation travels through our nerves 93 feet per second. Suppose that a child possessing an arm of extraordinary length should put it forth and touch the sun; he would need to live to be 164 years old if he ever learned that he was burned.

A falling body on the earth's surface will drop 16 feet the first second; on the sun it would fall 450 feet. A clock pendulum ticking seconds would quiver like a watch spring, and, according to Professor Young, "A graceful lady whose sylphlike form here would hardly weigh 100 pounds, if carried to the sun would become as unwieldy as an elephant, or rather would be crushed by her own weight. Her airy head alone would weigh 450 pounds!" On the earth a strong man can leap about a yard high; on the solar surface he could spring upwards about an inch, while it has been computed by Herschel that he could leap to the height of 60 feet on one of the minor planets.

The sun's diameter is about 110 times that of our earth. But this statement gives no notion as to its actual magnitude. Suppose the sun's center to coincide with the center of the earth. Then the solar surface would extend far beyond the path of the moon. In fact, the moon might move around in her orbit and

be nearly as far from the surface of the sun as from the earth. Suppose the sun a sphere 110 feet in diameter, then the earth would be a ball one foot in diameter, two miles away. On the same scale, the planet Jupiter would be ten miles away and twenty feet in diameter, Neptune 60 miles, and the nearest star nearly half a million of miles farther.

But all these comparisons become insignificant when we come to contemplate the enormous amount of radiant energy constantly emitted from the solar surface without apparent loss of power. At first it may seem difficult to understand how the heat given off by the sun can be measured, but I think a brief explanation will make it clear to all. Two measurements have been made, one by Sir John Herschel, at the cape of Good Hope, and the other by M. Pouillet, at Paris. According to the first authority the heating effects of a vertical sun would, at the sea level, be competent to melt 0.00754 of an inch of ice per minute. M. Pouillet obtained the number 0.00703 of an inch of ice per minute, or about a half an inch in an hour. And now as to the method. The instrument used is called a pyrheliometer. A shallow cylinder of steel filled with mercury is mounted on a rod. The mercury is coated with lampblack in order to cause all the rays to be absorbed. This blackened mercury is exposed to the direct rays of the sun for a few minutes and the increase in temperature noted. This multiplied by the weight of the mercury and its specific heat gives the number of thermal units received during the time the instrument was exposed. Knowing the area of the cylinder it is easy to compare it with the area of the entire surface of the earth exposed to the sun. It was found that about four-tenths of the sun's heat is absorbed by the atmosphere before it reaches the earth. Suppose, now, that the sun were enclosed in a spherical shell at the distance of the earth, it can be shown by calculation that the earth's surface is only the $\frac{1}{2,300,000,000}$ part of that shell. Therefore, the earth only captures one part in two billion, three hundred millions of the solar fire. It can further be shown that all the planets put together only intercept the $\frac{1}{225,000,000}$ part. Surely, this seems like

a great waste of energy. What would we think of a man who wasted two million dollars for each cent expended usefully? That, "Nature in filling a wine glass upsets a gallon," seems to be more than realized. Herschel illustrates the vigor of the solar fire in the following manner: Suppose a beam of ice 45 miles in diameter to be darted at the sun with the velocity of light, and that, in some way, the entire heat of the sun could be concentrated upon the advancing column. It would never reach the sun at all but would melt as fast as it approached. Or, again, suppose an ice bridge were built from the earth to the sun. Let its base be two miles square, and recall the fact that for the swiftest railway train to span this enormous interval of 90,000,000 miles, would require, without a single stop, more than 360 years; and now upon this mighty beam of polar ice let the sun concentrate all his rays. "The pendulum swings but *once*; in *one second* it has melted, and before the ninth beat of the clock it has completely vanished, dissipated in vapor. Such is the solar fire!"

Says Professor Tyndall, "The heat emitted by the sun, if used to melt a stratum of ice applied to the sun's surface, would liquify the ice at the rate of 2,400 feet per hour. It would boil, per hour, 700,000 millions of cubic miles of ice cold water. Expressed in another form, the heat given out by the sun, per hour, is equal to that which would be generated by the combustion of a layer of solid coal, 10 feet thick, entirely around the sun; hence, the heat emitted in a year is equal to that which would be produced by the combustion of a layer of coal 17 miles in thickness."

Such are the results deduced from actual measurements. But, now comes up the great question as to how this heat is maintained. Geology points millions of years into the past and affirms that the same sun which sheds upon us light and heat to-day has always held sway over the affairs of life on the earth. Is the sun a body which radiates heat without cooling? Is it a veritable perpetual motion on a grand scale? May not its heat be due to chemical action? It can be proved that, were the sun solid

coal and furnished with sufficient oxygen to unite with it, it could only last 5,000 years, at its present rate of cooling. And yet, we know the sun has been cooling for five thousand times five thousand years. No known substance upon the earth could produce a tithe of this heat. Where, then, shall we look for a solution? There have been proposed two theories to account for this enormous and incessant solar radiation. The first is known as the *meteoric theory of the sun* and is due to a German physician named Mayer. All of you are aware that the heavens swarm with comets, meteors, moons and planets. Not a night passes in which so-called shooting stars cannot be seen in our atmosphere, lighting up the sky and sometimes accompanied by fearful explosions and bright corruscations. Generally, these visitors from space are dissipated in vapor on striking our atmosphere and never reach the earth. Sometimes, however, they fall as meteoric stones of great weight. It is highly probable that most of them seen are due to gaseous bodies which come in collision with our atmosphere. Comets are thought by some to consist, at times, of innumerable solid bodies grouped together and pursuing a common track about the sun. The *Zodiacal light*, which is a faint belt of light seen in the west after sun-set and in the east before sun-rise, is supposed to be due to reflected light from millions of miniature planets revolving about the sun within the orbit of Mercury.

While studying the phenomena of light we learned that celestial space is filled with a medium which seems to resist the motions of the lighter bodies which revolve about the sun. Encke's comet, which has a period of three and a half years, gains in each revolution about six hours. The final result can easily be foretold. Slowly but surely the planets and comets must creep toward the great central fire. For such a planet as our earth the resistance of the medium would be exceedingly small; perhaps requiring thousands of years to make the change in its velocity appreciable. The swiftest motions with which we are familiar, as, that of a bullet, are about 1200 feet per second. But the earth moves in its orbit

nearly 20 miles in a second, or 90 times the velocity of a bullet. Fancy the crash produced if such a projectile should strike the sun. According to Mayer, an asteroid, by its fall into the sun, develops from 4,600 to 9,200 times the heat that would be generated by the combustion of an equal mass of solid coal.* It becomes of little importance, therefore, whether the asteroid be made of combustible material or not. Now, according to the author of the *meteoric theory*, the heat of the sun is sustained by the constant falling of these meteoric masses. If a body fall to the sun from the extreme limits of our solar system its final velocity, just before reaching the sun's surface, would be 85 geographical miles, or about 350 English miles per second.† While the least velocity a meteorite would be likely to have is 240 miles per second. Great discordance exists as to the temperature of the sun. The majority of physicists put the probable figure at from 5,000° to 20,000° C. The highest temperatures with which we are familiar are perhaps from 2,000° to 3,000° C. We know, however, that the temperature of the solar surface must be enormously high. From the elementary principles of Physics we learn that the temperature of a body in the focus of a lens cannot become higher than that of the source of heat. But, in the focus of a lens three feet in diameter, platinum, the diamond, fire-clay and the most stable substances can be melted by the solar rays.

There can be little doubt that were the sun brought as near the earth as the moon, the elements of the earth itself would melt.‡ But in the fall of cosmical masses, we find it easy to account for this enormous supply of energy. Millions of comets, asteroids and miniature planets are continually creeping towards the sun, finally to become entangled in his dense atmosphere and flash forth into space as light and heat the tremendous kinetic energy possessed a few moments before. Below is given a table, calculated by Sir William Thomson, showing the heat of gravita-

* Mayer's "Celestial Dynamics," Correlation of Forces, p. 276.

† Mayer's "Celestial Dynamics," Correlation of Forces, p. 274.

‡ Prof. C. A. Young, "University Series," p. 160.

tion of the planets; in other words, the heat which would be produced by the several planets if they should stop moving in their orbits and fall into the sun:

HEAT OF GRAVITATION EQUAL TO
SOLAR EMISSION FOR :

Mercury.....	6 years, 214 days
Venus.....	83 " 227 "
Earth.....	94 " 303 "
Mars.....	12 " 252 "
Jupiter.....	32,240 "
Saturn.....	9,650 "
Uranus.....	1,610 "
Neptune.....	1,890 "

From the above it will be seen that our earth, in plunging into the solar center, would furnish heat enough to last for nearly a century. Jupiter would supply it for 32,000 years, and all the planets together for more than 45,000 years. It can be shown, according to Helmholtz, that the shock produced by bringing the earth to rest in its orbit would produce more heat than the combustion of fourteen such earths of solid coal. The temperature of the earth would be raised 11,200 degrees, and it would, therefore, be completely fused and perhaps reduced to vapor. But the heat developed by the subsequent fall of our planet into the sun would be four hundred times greater than the above.* "Whatever be the ultimate fate of the theory here sketched," says Professor Tyndall, speaking of the meteoric theory of Mayer, "it is a great thing to be able to state the conditions which certainly would produce a sun,—to be able to discern in the force of gravity, acting upon dark matter, the source from which the starry heavens *may* have been derived. For, whether the sun be produced and his emission maintained by the collision of cosmical masses,—whether the internal heat of the earth be the residue of that developed by the impact of cold, dark asteroids, or not, there cannot be a doubt as to the competence of the cause assigned to produce the effects ascribed to it. Solar light and solar heat lie latent in the force which pulls an apple to the ground. Created simply as a difference of position of attracting masses, the potential energy of gravitation was the

* Helmholtz in "Interaction of Natural Forces."

original form of all the energy in the universe. As surely as the weights of a clock run down to their lowest position, from which they can never rise again unless fresh energy is communicated to them from some source not yet exhausted, so surely must planet after planet creep in, age by age, towards the sun."

"When each comes within a few hundred thousand miles of his surface, if he is still incandescent, it must be melted and driven into vapor by radiant heat. Nor, if he be crusted over and become dark and cool externally, can the doomed planet escape his fiery end. If it does not become incandescent, like a shooting star, by friction in its passage through his atmosphere, its first graze on his surface must produce a stupendous flash of light and heat. It may be at once, or it may be after two or three bounds, like a cannon shot ricochetting on a surface of earth or water. The whole mass must be crushed, melted, and evaporated with a crash, generating in a moment some thousands of times as much heat as a coal of the same size would produce by burning."

The second theory is due to Helmholtz an eminent German mathematician, physicist and physiologist, and is called the *condensation theory*. All of us are familiar with the fact that the physical state of matter is simply a question of temperature. Water is a solid at the poles of the earth, a liquid at the equator, while upon the sun, if it exists, it must be as vapor. Mercury is usually a liquid, below 40° it is a solid, while at temperatures above 350° Centigrade it is a vapor. At the will of the physicist, almost all known substances may be made to assume either the solid, liquid or gaseous states. Now, according to the nebular hypothesis of Laplace, all the matter of the solar system was once in a highly attenuated gaseous condition and stretched in a nearly homogeneous mass far beyond the present orbit of the most distant planet, Neptune. "If we calculate," says Helmholtz, "the density of the mass of our planetary system, according to the above assumption, for the time when it was a nebulous sphere, which reached to the path of the outmost planet, we should find that it would require several cubic miles to weigh a

single grain." This corresponds to a density of many million of times less than hydrogen gas, the lightest known substance. Astronomers tell us of patches of nebulous matter, brought into view by powerful telescopes, which resemble the possible conditions of our system during its formative stages. Through the action of well known physical laws the planets, satellites, comets and asteroids, as well as the central sun, have been evolved from this primitive nebula. The sun has shrunk in diameter from 6,000,000,000 of miles to less than 1,000,000. Now condensation produces heat. Tinder can be lighted by the simple compression of air. This enormous condensation represents so much fall of material particles. It is a change from potential to active or heat energy.

* "Assuming that, at the commencement, the density of the nebulous mass was a vanishing quantity, as compared with the present density of the sun and planets; we can then calculate how much work has been done by the condensation; we can further calculate how much of this work still exists in the form of mechanical force, as attraction of the planets toward the sun and as the *kinetic energy* of their motion, and find, by this, how much of the force has been converted into heat." The result of the calculation shows that all but $\frac{1}{454}$ part has been lost; radiated into the depths of space. That which has been lost would raise the sun and planets to a temperature of 28,000,000° Centigrade supposing them to have a specific heat equal to water. Were the entire system pure coal its complete combustion would furnish but the $\frac{1}{3,500}$ part of the above quantity of heat. According to the same authority this condensation of the sun is still going on. Its particles are still falling down towards the center of gravity and and thereby generating heat. Helmholtz shows that the shrinking of the diameter of the sun by the $\frac{1}{10,000}$ part of its present length would generate a supply of heat which would cover the present emission for 2,000 years. While, should it shrink so much that its mean density was equal to that of our earth the

* Helmholtz in "Interaction of Natural Forces."

heat generated would supply us with our present quota of solar radiation for 17,000,000 of years!!

The truth of the matter doubtless lies between the two theories. In fact, they are resolvable into one common cause—the conversion of the potential energy of gravitation into heat energy. In the first theory, the falling of cosmical *masses*, and, in the second, of cosmical *particles*, account for the effects. There is little doubt that both actions are constantly in progress. Whether true or not, these conclusions of Helmholtz cannot but give us an exalted notion of the power possessed by the physicist with which to fathom the mysteries of the universe. They give us the exact conditions which *would* produce a sun. And we know that all accessible evidence points to a primordial state of matter such as that indicated by the nebular theory. What ages must have elapsed since that time! How long will it continue thus? Experiments by Bischof on the cooling of basalt show that 350,000,000 years would be required for our earth to cool from 2,000° to 200° Centigrade. And yet Geology points to a time when the planet we inhabit was in a liquid state; and, if so, it must have cooled as indicated above. Astronomers look back still farther than this, and see the earth a vast sphere of gaseous matter reaching to the orbit of the moon and including that luminary as a part of herself. But how vaguely does all this give us a notion of the centuries which must have preceded, when the sun and planets were involved in the same homogeneous vapor.

The forms of energy with which we are acquainted are as follows: energy of fuel, food, a head of water, wind, and currents of water. This enumeration includes the important forms of terrestrial energy, and, as must be evident to every one, the sun is the prime cause of all. Fuel and food are both produced at the expense of solar heat. The winds are stirred by the same power. Water is evaporated and raised to high levels by the sun, finally to fall as rain on hills and mountains and be utilized in running our millstones. Thus you can see that there is no avoiding the conclusion that the sun is the prime cause of

all terrestrial motion. Not only did God make the sun to give us light, but He has placed in that orb all the forms of activity known to man. Look what way we may—to the forests for fuel, to our coal for steam power, the beasts for muscular energy, or even to the winds of the air—all depend upon the same great Force-Center for every iota of energy furnished. Regarded in this light, that mass of shining matter becomes to us of immense significance. If the sun in his present state is to be eternal, then are life and motion and earthly progress practically infinite in duration. If the sun does not burn always, then just so surely must all earthly life and motion sink into an eternal sleep; at least, so far as science is able to lead us. And now we will briefly examine this question.

Dissipation of Energy.—If no force can ever be lost, it becomes a question of interest as to what becomes of the enormous radiant energy of the sun. We regard heat and work as mutually convertible. If I rub a button forcibly on some smooth surface, it becomes hot; mechanical energy becomes heat energy. But, can I transform this heat of the button back again into work? Evidently, no. And here you may recall to mind the important fact that, in every case when heat is made to do work, it must be high temperature heat. There is no possible method of transforming all the heat of mechanical energy into work. If available, heat must be of high intensity. Suppose we have two reservoirs of water, one being much above the other. In falling down to the lower level, the upper reservoir will do work; but once on the same level as the other, and its available energy is all gone. Thus, suppose we have two boilers, one at a high and the other at a low temperature. By passing steam from the higher to the one of lower temperature, work can be done, but when once the temperatures of the two are the same, their heat is useless. And yet we might be able to prove that no force had been lost. The boiler of low temperature would have gained as much as the other lost, less the work done. Now, this is an illustration of what is continually going on in the physical universe. Heat is never lost. It is dissipated, scattered. The en-

ergy of the universe tends constantly to be changed into this form of universally diffused heat of low temperature. The universe is a clock which has been wound up. It is now running down. The weights are almost to the bottom. Will the clock finally cease to run? Surely this question is worth considering.

All motion is mechanical. The movements of the moons and planets of our solar system are controlled by the same laws that apply to the motions of a steam engine, and the astronomer can calculate them with equal certainty. All terrestrial energy, if we except that of the tides, is derived from that of the sun. The question is, therefore, resolved into this, is the sun a perpetual motion? Will its supply of fuel last forever? On any of the hypotheses we are compelled to answer in the negative. The potential energy of separated particles is yearly becoming less. The sun is cooling off. Universally diffused heat has been called the great "waste heap" of the universe, and it is the dictate of science that all known forms of energy are continually tending to augment the size of that heap. Indeed, we need to leave the earth but a short distance to see that this cooling process is actually in progress. The moon is a case in point. That satellite of the earth exhibits upon its surface numerous evidences that it was once the seat of the most violent igneous action. The lunar mountains and craters are on a scale so grand that Hecla and Vesuvius sink into insignificance. And yet all traces of life and activity have disappeared. The moon is a planet in ruins, a cold, lifeless lump. That a similar state is awaiting the earth and, finally, the sun seems to be the inevitable conclusion of modern science. *

* NOTE.—Of course it must be evident to all that a universe, subject to the well known laws of heat, must have had a beginning and will have an end. All manifestations of energy, all activity, must ultimately cease in such a universe. And quiescence is death; eternal silence is eternal death. The human mind shrinks from the contemplation of a universe so constituted; and yet we must admit that the laws of heat, on which the conclusion is based, are perhaps the best understood of any in science. Professor Rankine has made a bold suggestion as to a manner in which, by a break of continuity, the store of available energy in the universe may be replenished. If the ether which transmits

Says the distinguished Helmholtz, "Though the store of our planetary system is so immense that it has not been sensibly diminished by the incessant emission which has gone on during the period of man's history, and though the time which must elapse before a sensible change in the condition of our planetary system can occur, is totally beyond our comprehension, the inexorable laws of mechanics show that this store, which can only suffer loss and not gain, must finally be exhausted. Shall we terrify ourselves by this thought? We are in the habit of measuring the greatness of the universe, and the wisdom displayed in it, by the duration and the profit which it promises to our own race; but the past history of the earth shows the insignificance of the interval during which man had his dwelling here. What the museums of Europe show us of the remains of Egypt and Assyria we gaze upon with silent wonder, in despair of being able to carry back our thoughts to a period so remote. Still, the human race must have existed and multiplied for ages before the Pyramids could have been erected. We estimate the duration of human history at 6,000 years; but, vast as the time may appear to us, what is it in comparison with the period during which the earth bore successive series of rank plants and mighty animals, but no men? * * Different geologists have, from different premises, sought to estimate the length of the above period, and they set it down from one to nine millions of years. The time during which the earth has generated organic beings is again small, compared with the ages during which the world was a mass of molten rock, and with regard to the period during which the first nebulous mass condensed, to form our planetary system, conjecture must entirely cease."

radiant energy be not infinite in extent it must have bounds. All oscillations, on reaching that boundary, would be totally reflected, and the form of the the exterior surface might be such as to concentrate these rays into great foci. A lifeless star, in passing through such a focus, would become ignited and thus get a supply of energy sufficient to last it for centuries. Thus, by frequent breaches of continuity, the Physical Universe might be sustained forever.









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